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(12) **United States Patent**
Trott et al.

(10) **Patent No.: US 8,442,019 B2**
(45) **Date of Patent: May 14, 2013**

(54) **METHOD AND APPARATUS FOR AVOIDING WIRELESS AUDIO SIGNAL TRANSMISSION INTERFERENCES**

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(73) Assignee: **Bose Corporation**, Framingham, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 2154 days.

(21) Appl. No.: **11/050,160**

(22) Filed: **Feb. 3, 2005**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation-in-part of application No. 10/640,215, filed on Aug. 12, 2003.

(51) **Int. Cl.**
H04B 7/216 (2006.01)

(52) **U.S. Cl.**
USPC **370/342**; 455/447; 455/454

(58) **Field of Classification Search** 455/450; 370/341
See application file for complete search history.

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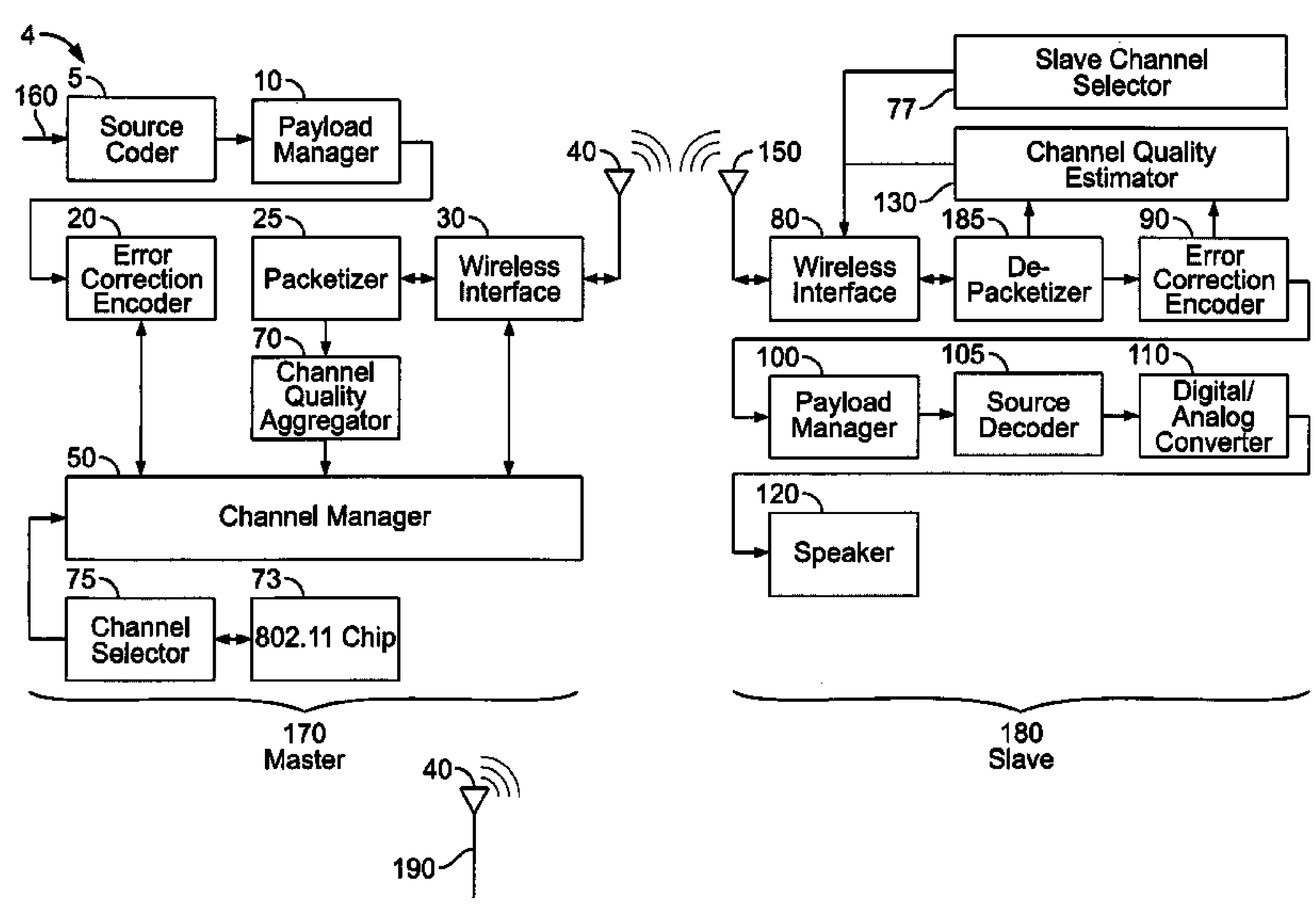
Primary Examiner — Marcos Batista
(74) *Attorney, Agent, or Firm* — Fish & Richardson P.C.

(57) **ABSTRACT**

In one aspect, in general, the invention features a method including a second wireless system determining a frequency of active operation of a first wireless system, and communicating wirelessly on the second wireless system in the vicinity of the wireless communication on the first wireless system, the wireless communication utilizing a spread-spectrum technique that excludes the determined frequency.

15 Claims, 24 Drawing Sheets



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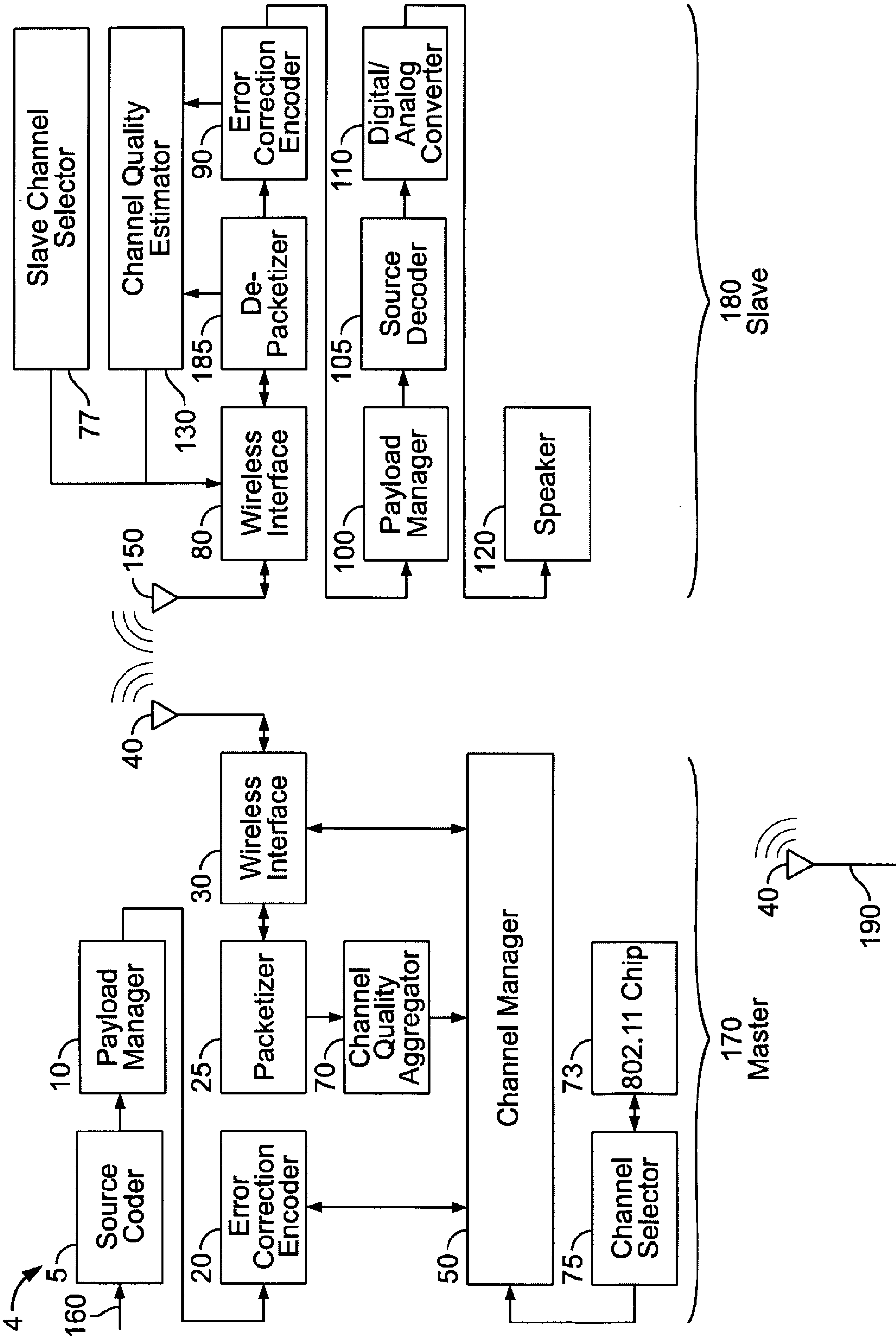

4
160
5
Source Coder
10
Payload Manager
20
Error Correction Encoder
25
Packetizer
30
Wireless Interface
40
70
Channel Quality Aggregator
50
Channel Manager
75
Channel Selector
73
802.11 Chip
170
Master
40
190
150
80
Wireless Interface
130
Channel Quality Estimator
77
Slave Channel Selector
185
De-Packetizer
90
Error Correction Encoder
100
Payload Manager
105
Source Decoder
110
Digital/ Analog Converter
120
Speaker
180
Slave

FIG. 1

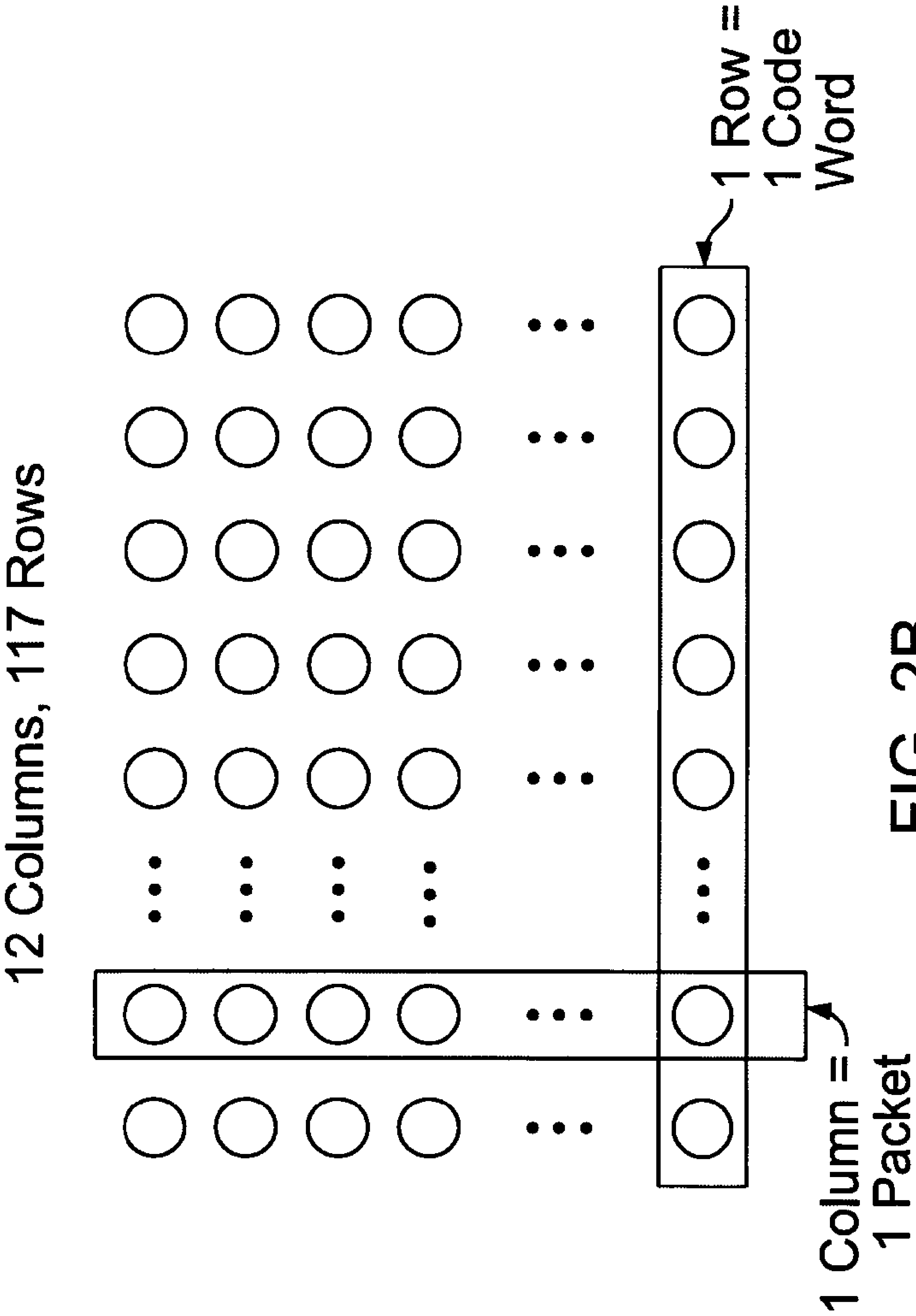


FIG. 2B

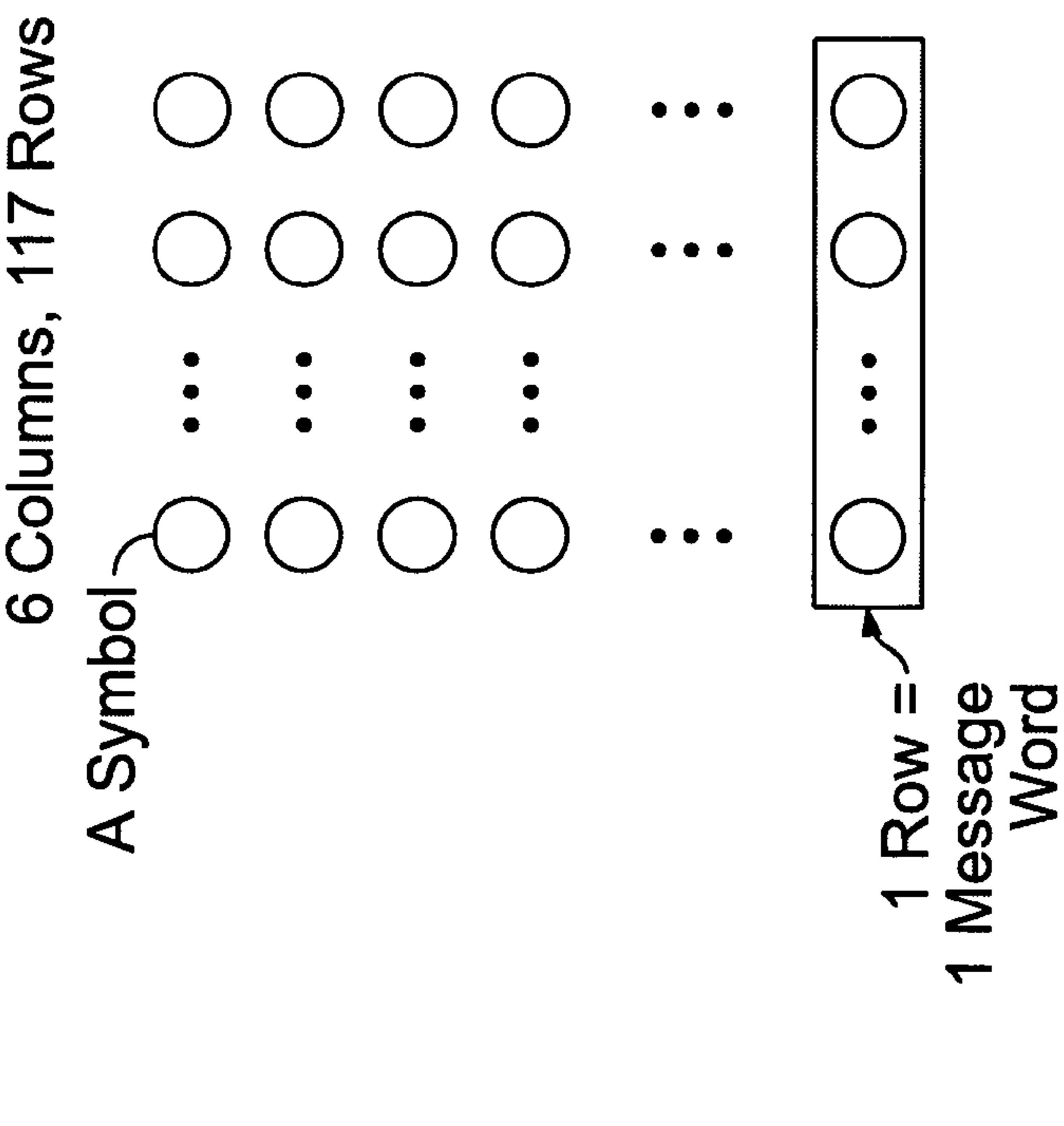


FIG. 2A

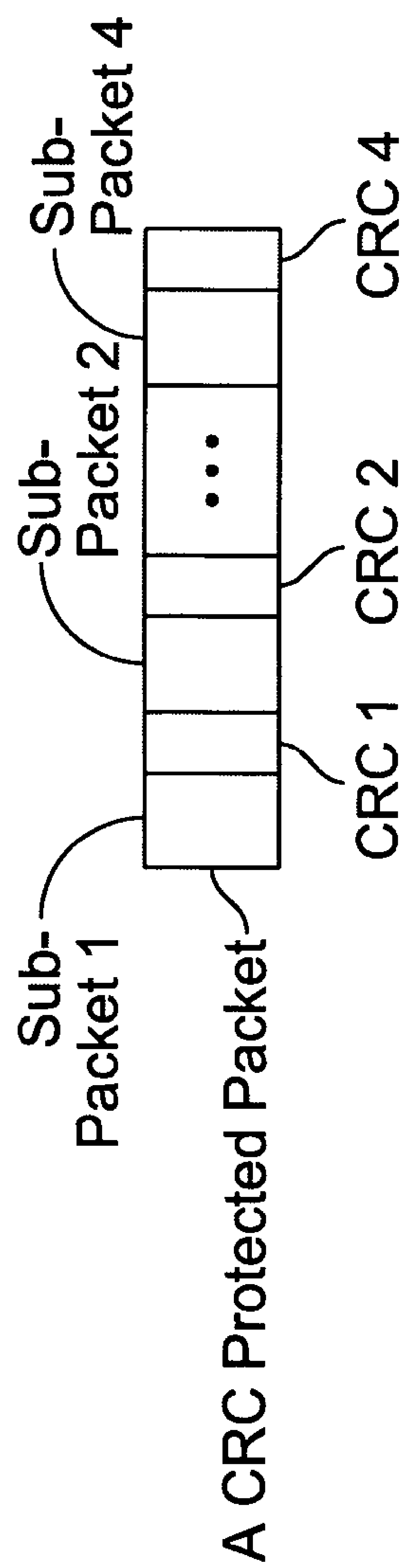


FIG. 2C

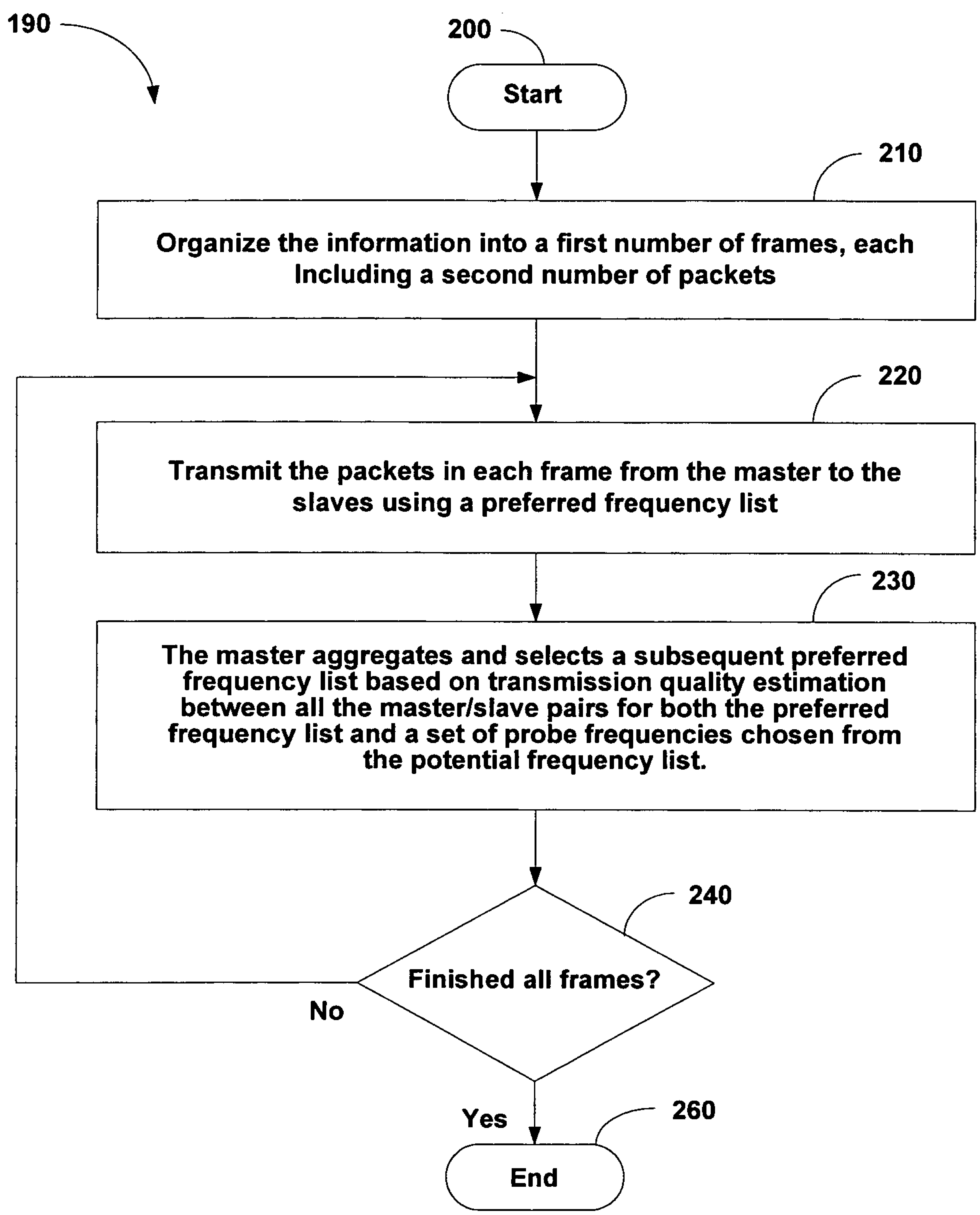

190
200
Start
210
Organize the information into a first number of frames, each Including a second number of packets
220
Transmit the packets in each frame from the master to the slaves using a preferred frequency list
230
The master aggregates and selects a subsequent preferred frequency list based on transmission quality estimation between all the master/slave pairs for both the preferred frequency list and a set of probe frequencies chosen from the potential frequency list.
240
Finished all frames?
No
Yes
260
End

FIG. 3

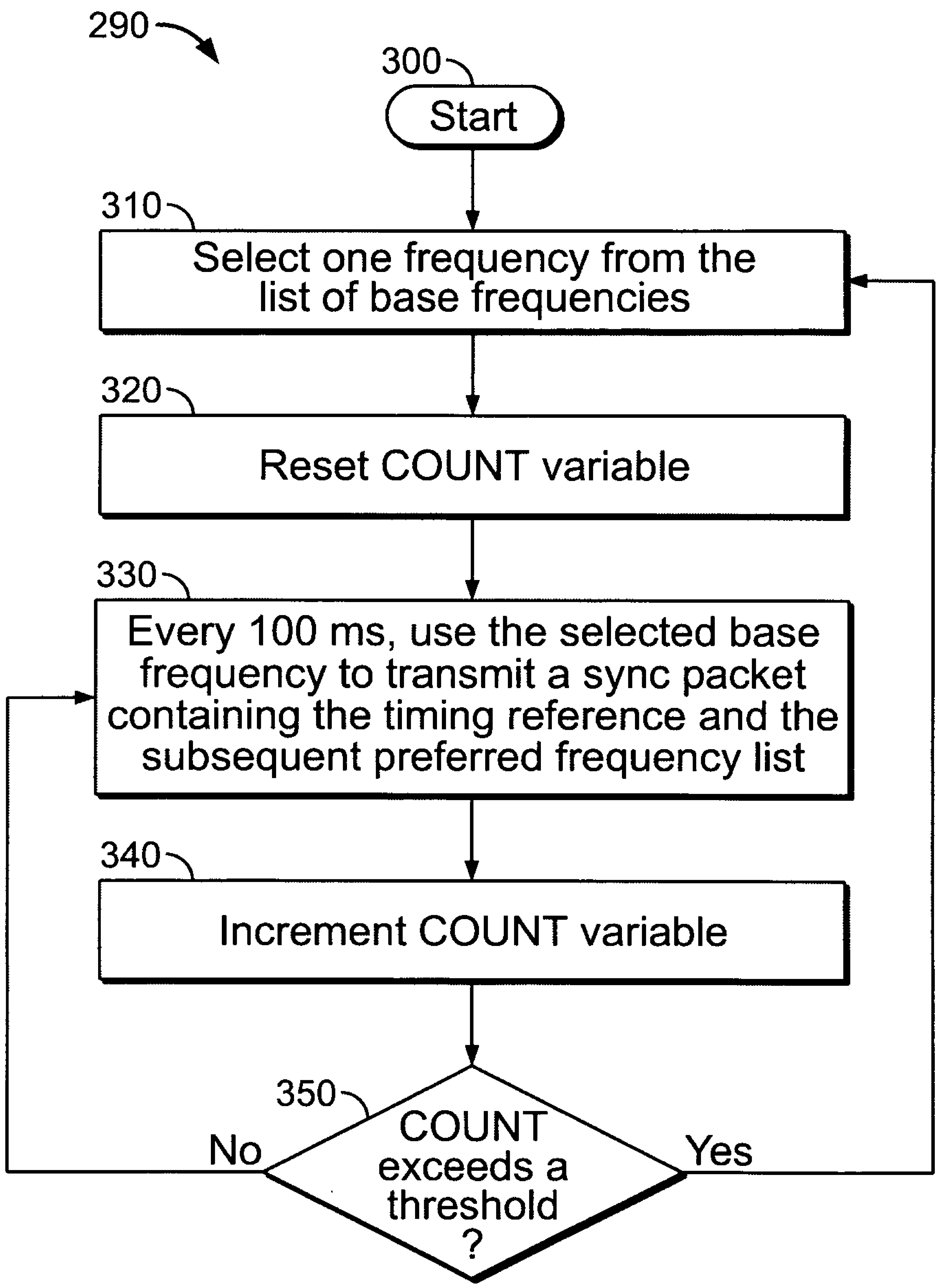

290
300
Start
310
Select one frequency from the list of base frequencies
320
Reset COUNT variable
330
Every 100 ms, use the selected base frequency to transmit a sync packet containing the timing reference and the subsequent preferred frequency list
340
Increment COUNT variable
350
COUNT exceeds a threshold ?
No
Yes

FIG. 4A

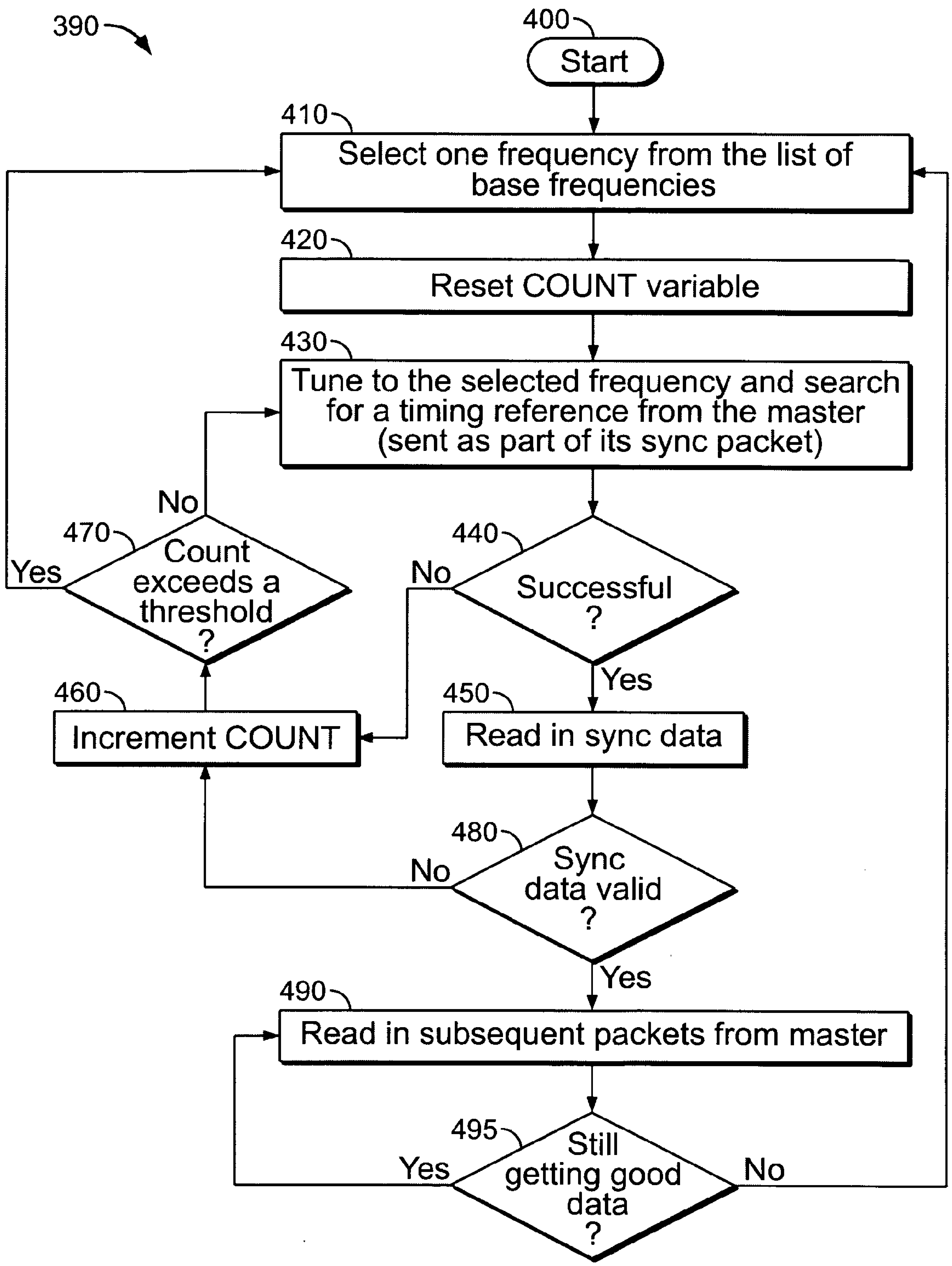

390
400
Start
410
Select one frequency from the list of base frequencies
420
Reset COUNT variable
430
Tune to the selected frequency and search for a timing reference from the master (sent as part of its sync packet)
440
Successful ?
No
Yes
450
Read in sync data
470
Count exceeds a threshold ?
No
Yes
460
Increment COUNT
480
Sync data valid ?
No
Yes
490
Read in subsequent packets from master
495
Still getting good data ?
Yes
No

FIG. 4B

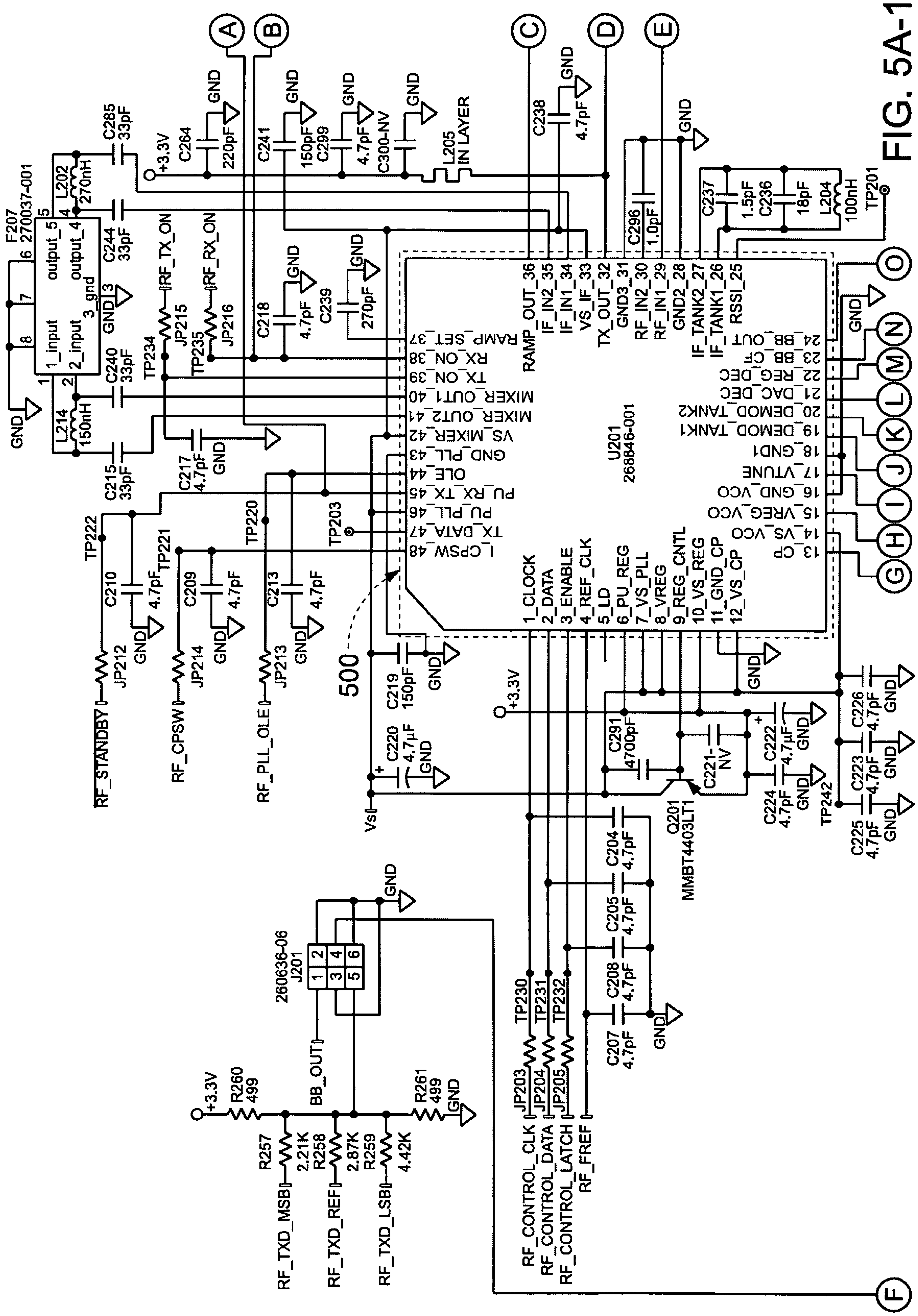


FIG. 5A-1

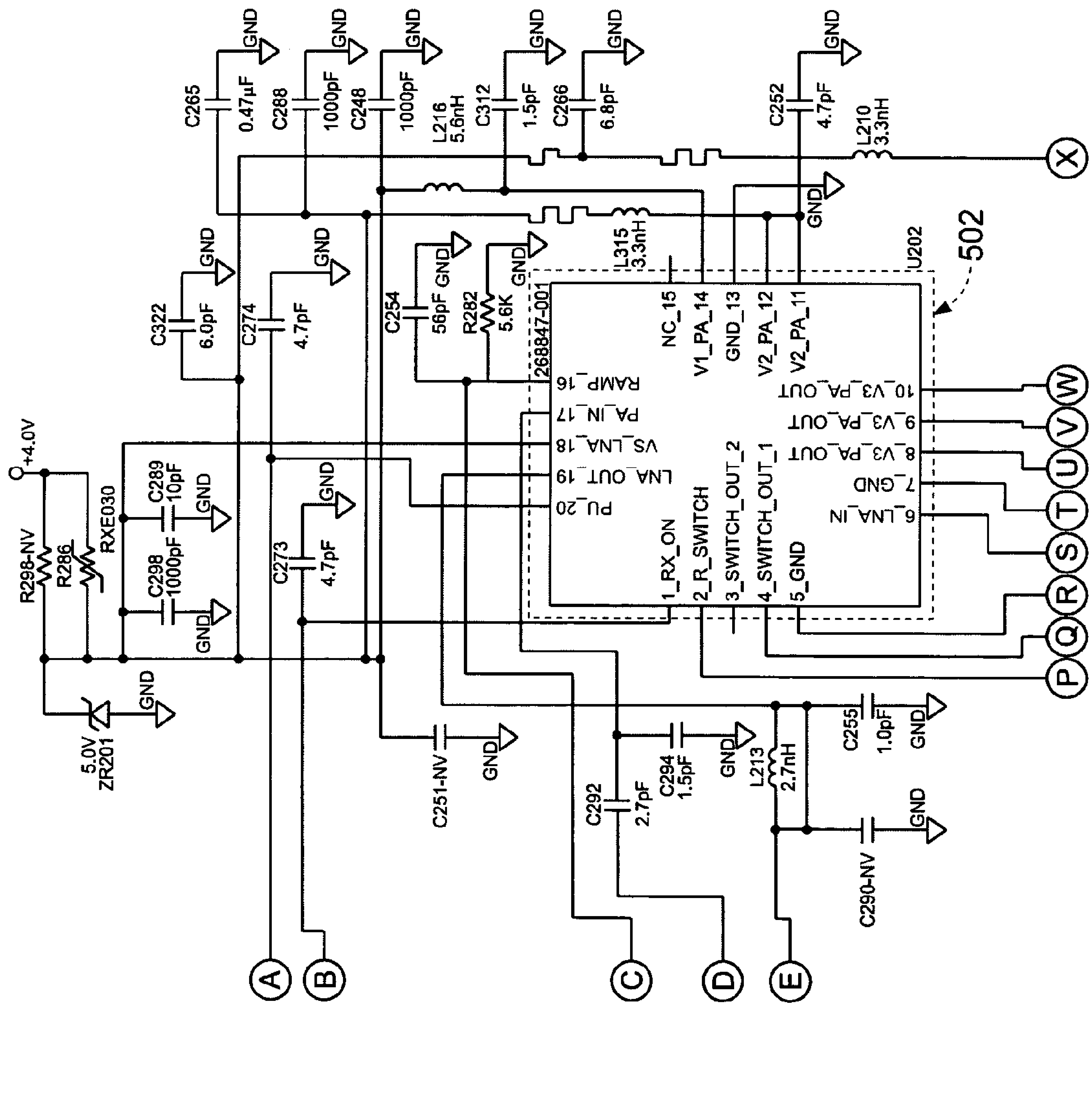


FIG. 5A-2

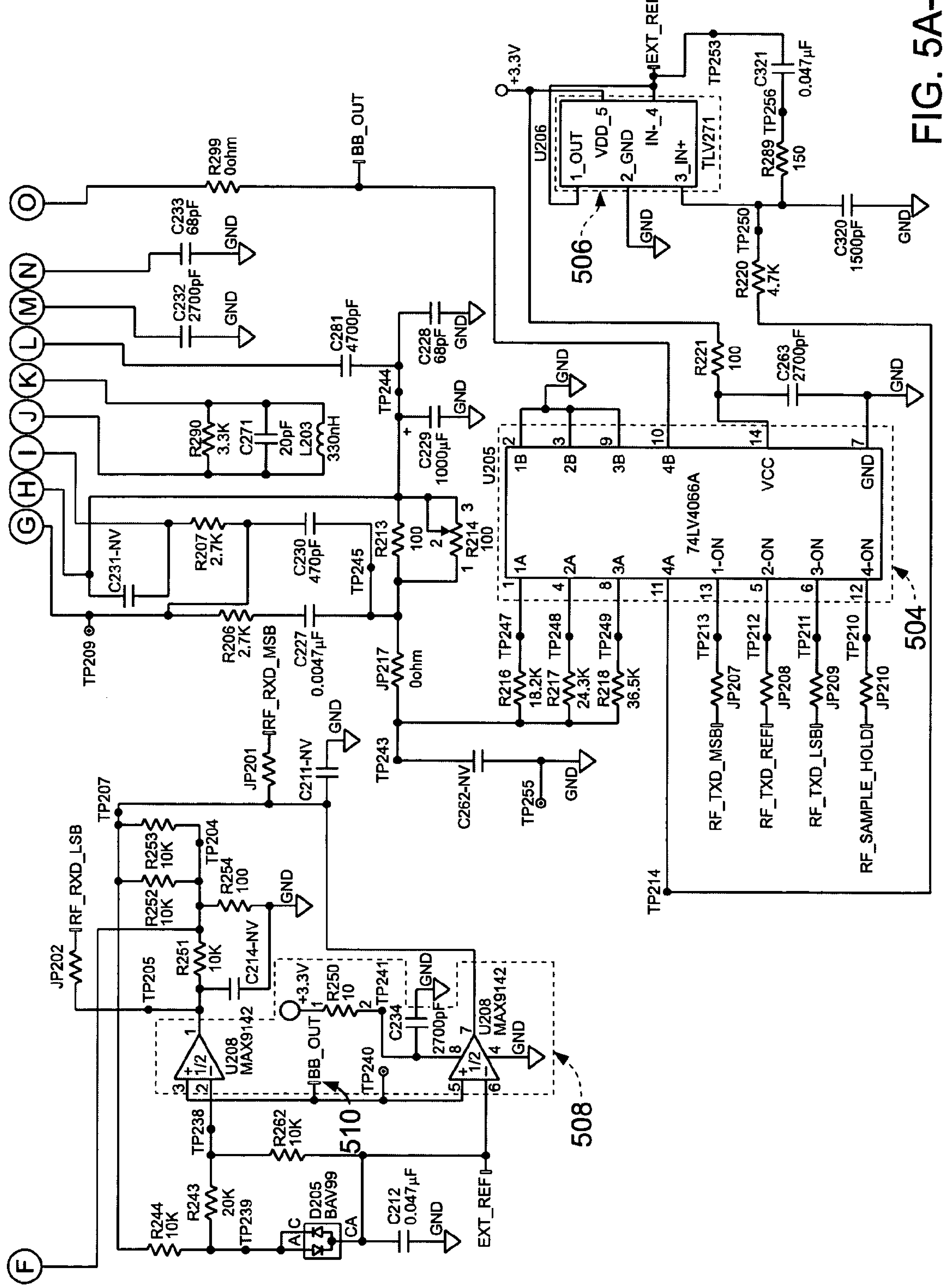

74LV4066A
U205
U206
TLV271
U208
MAX9142
BB_OUT
EXT_REF
+3.3V
GND
RF_RXD_MSB
RF_RXD_LSB
RF_TXD_MSB
RF_TXD_REF
RF_TXD_LSB
RF_SAMPLE_HOLD
D205
BAV99
504
506
508
510

FIG. 5A-3

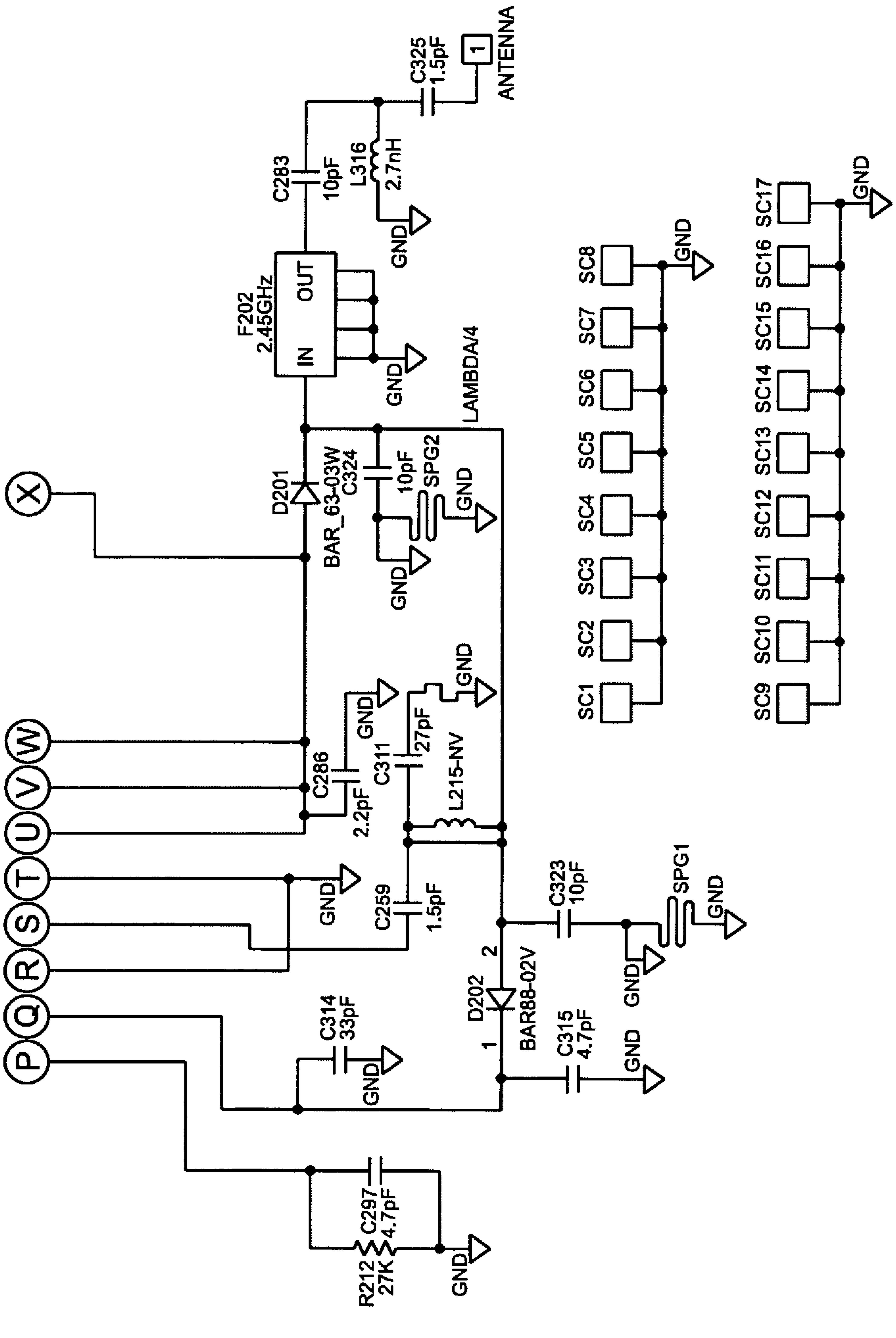

ANTENNA
C325
1.5pF
C283
10pF
L316
2.7nH
GND
F202
2.45GHz
IN
OUT
LAMBDA/4
D201
BAR_63-03W
C324
10pF
SPG2
C286
2.2pF
C311
27pF
L215-NV
C259
1.5pF
C323
10pF
SPG1
D202
BAR88-02V
C314
33pF
C315
4.7pF
C297
4.7pF
R212
27K
P
Q
R
S
T
U
V
W
X
SC1
SC2
SC3
SC4
SC5
SC6
SC7
SC8
SC9
SC10
SC11
SC12
SC13
SC14
SC15
SC16
SC17

FIG. 5A-4

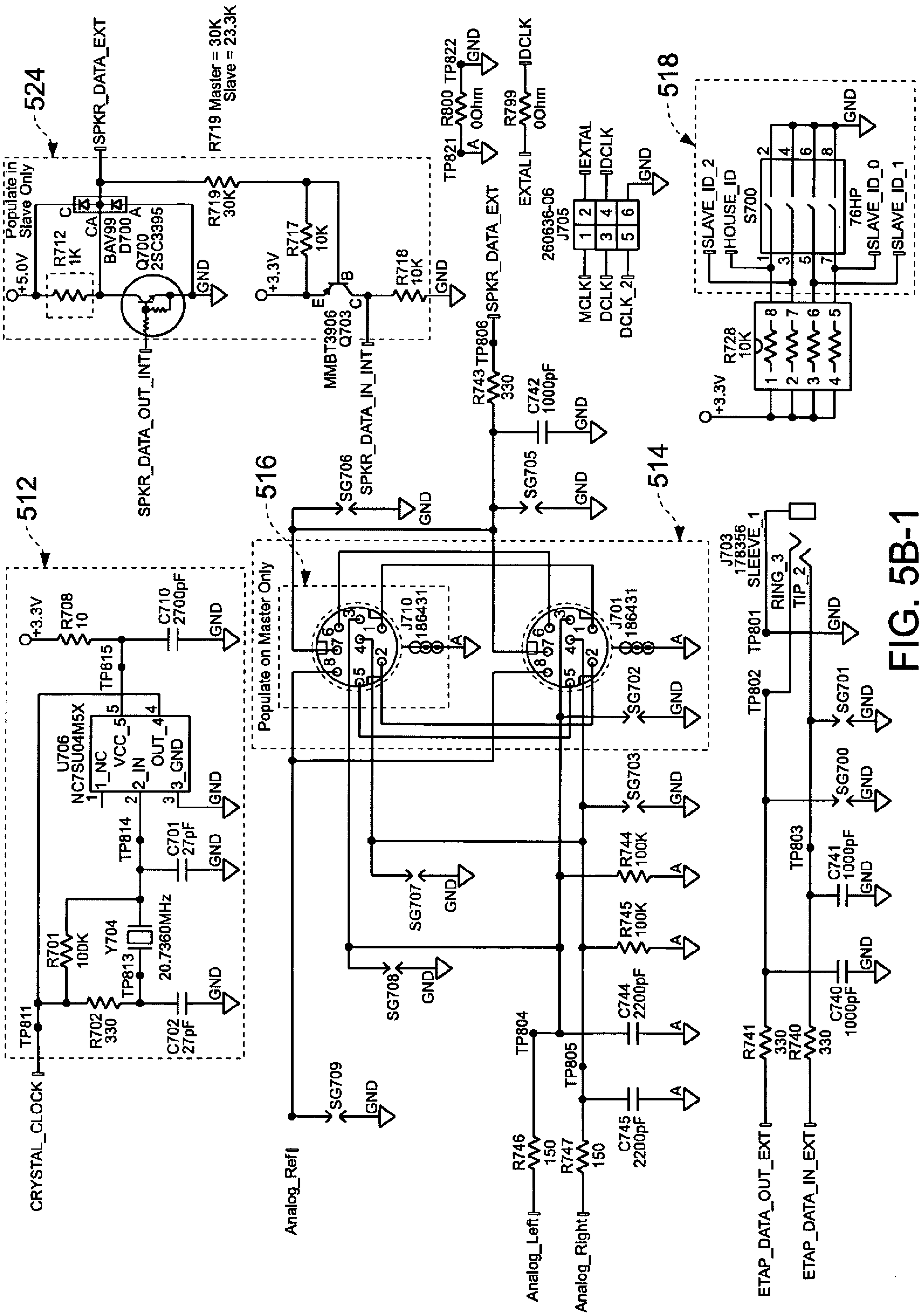
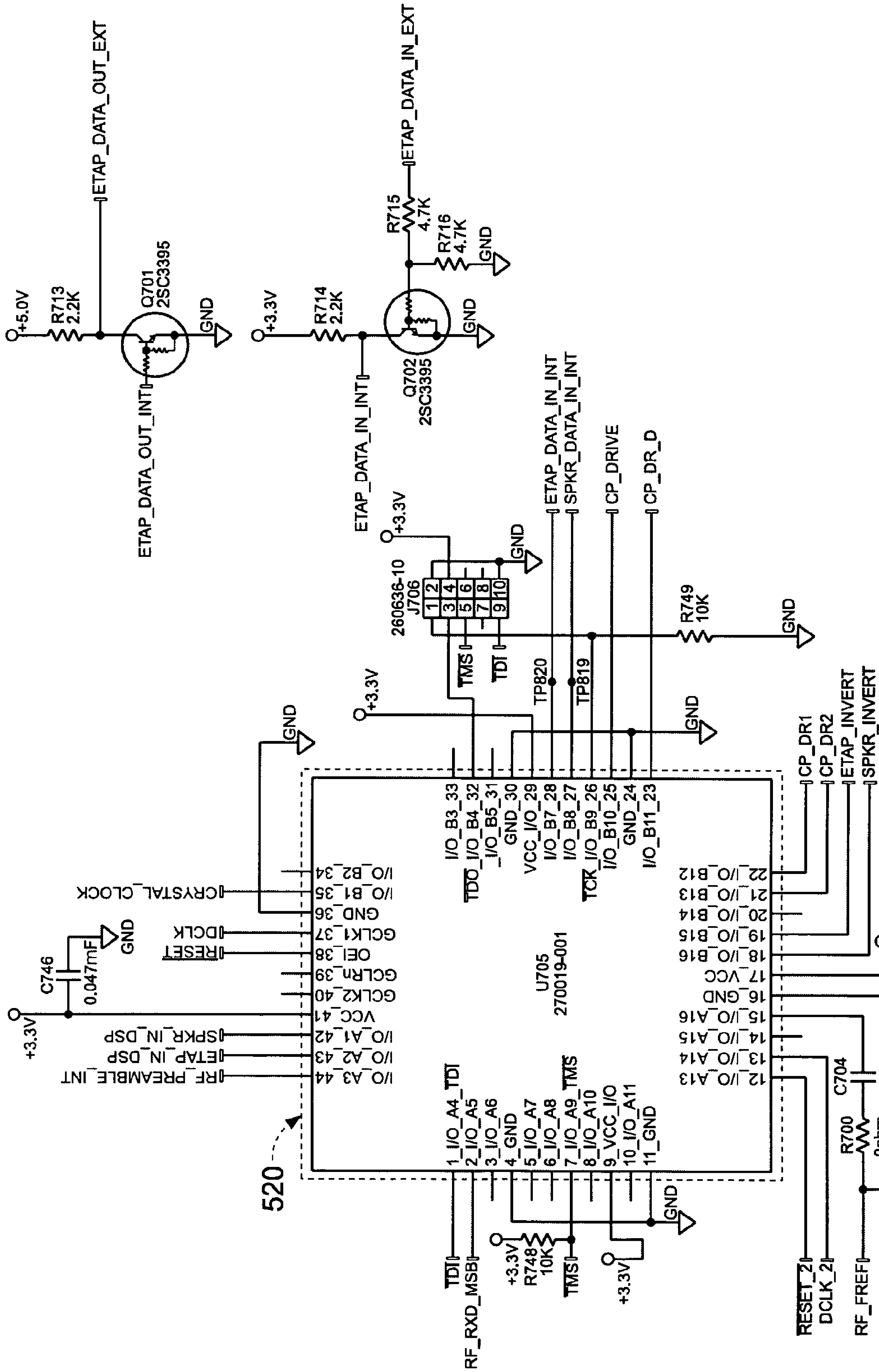

524
SPKR_DATA_EXT
R719 Master = 30K
Slave = 23.3K
Populate in Slave Only
+5.0V
R712 1K
C CA A
BAV99 D700
Q700 2SC3395
GND
R719 30K
+3.3V
R717 10K
E B C
R718 10K
MMBT3906 Q703
SPKR_DATA_OUT_INT
SPKR_DATA_IN_INT
TP821 R800 0Ohm TP822
A GND
EXTAL R799 0Ohm DCLK
260636-06 J705
MCLK DCLK DCLK_2
EXTAL DCLK GND
SPKR_DATA_EXT
518
SLAVE_ID_2 HOUSE_ID S700 76HP SLAVE_ID_0 SLAVE_ID_1
R728 10K
+3.3V
512
+3.3V R708 10
C710 2700pF
TP815
U706 NC7SU04M5X
1_NC VCC_5 2_IN OUT_4 3_GND
TP814 C701 27pF
R701 100K
Y704 20.7360MHz
TP813
TP811 R702 330 C702 27pF
CRYSTAL_CLOCK
516
SG706 GND
Populate on Master Only
J710 186431
R743 330 TP806
C742 1000pF
SG705 GND
514
J701 186431
SG702 GND
SG703 GND
R744 100K
SG707 GND
R745 100K
SG708 GND
TP804 C744 2200pF
TP805 C745 2200pF
SG709 GND
Analog_Ref
R746 150 R747 150
Analog_Left Analog_Right
J703 178356 SLEEVE_1 RING_3 TIP_2
TP801 GND
TP802 SG701 GND
SG700 GND
TP803 C741 1000pF
C740 1000pF
R741 330 R740 330
ETAP_DATA_OUT_EXT
ETAP_DATA_IN_EXT

FIG. 5B-1



ETAP_DATA_OUT_EXT
+5.0V
R713
2.2K
Q701
2SC3395
GND
ETAP_DATA_OUT_INT
ETAP_DATA_IN_EXT
R715
4.7K
R716
4.7K
+3.3V
R714
2.2K
Q702
2SC3395
ETAP_DATA_IN_INT
260636-10
J706
TMS
TDI
R749
10K
TP820
TP819
ETAP_DATA_IN_INT
SPKR_DATA_IN_INT
CP_DRIVE
CP_DR_D
CP_DR1
CP_DR2
ETAP_INVERT
SPKR_INVERT
C747
0.047mF
C746
0.047mF
CRYSTAL_CLOCK
DCLK
RESET
SPKR_IN_DSP
ETAP_IN_DSP
RF_PREAMBLE_INT
U705
270019-001
C704
56pF
R700
0ohm
C703-NV
R748
10K
RESET_2
DCLK_2
RF_FREF
RF_RXD_MSB
520

FIG. 5B-2

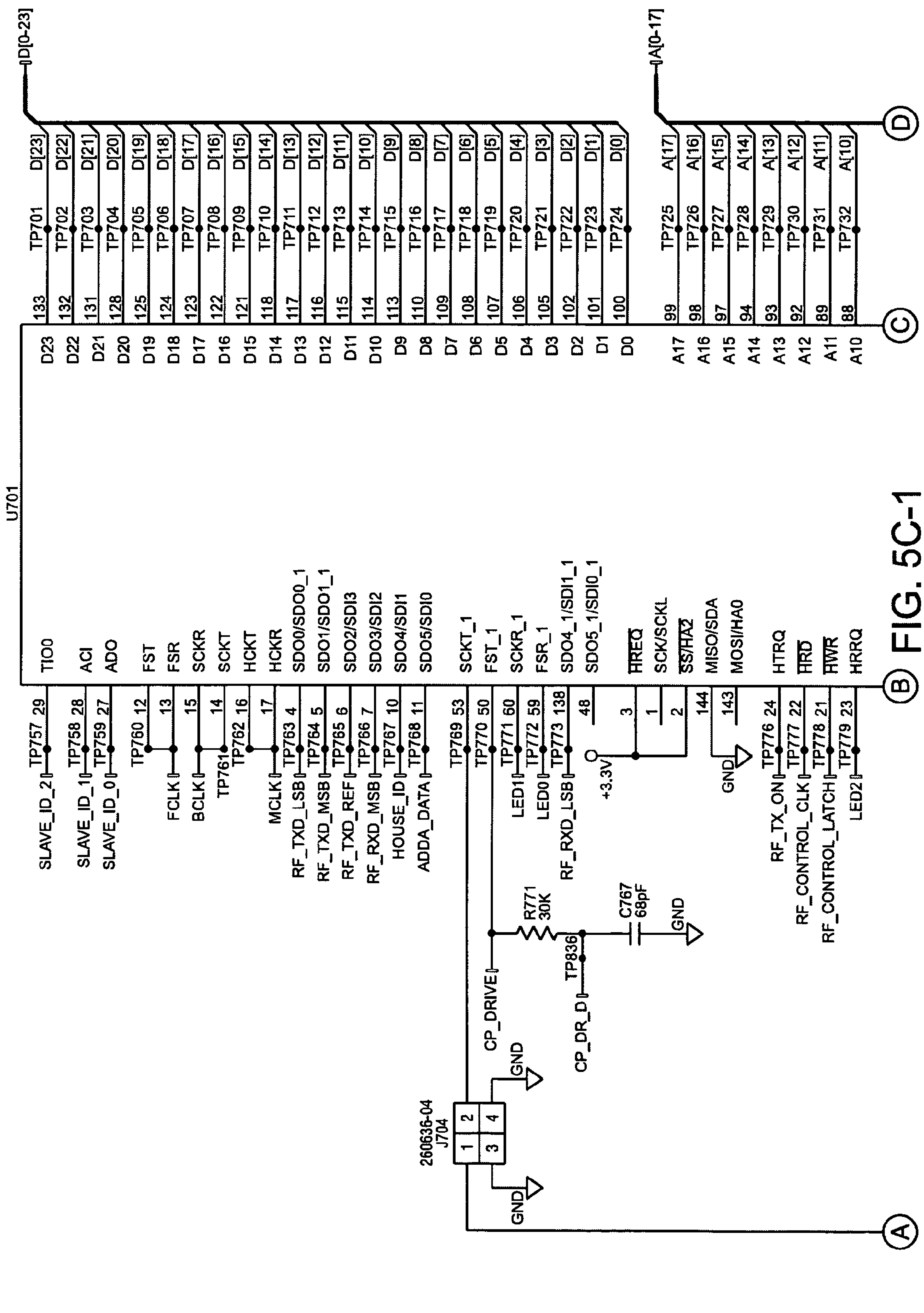

U701
D[0-23]
A[0-17]
D23
D22
D21
D20
D19
D18
D17
D16
D15
D14
D13
D12
D11
D10
D9
D8
D7
D6
D5
D4
D3
D2
D1
D0
A17
A16
A15
A14
A13
A12
A11
A10
TIO0
ACI
ADO
FST
FSR
SCKR
SCKT
HCKT
HCKR
SDO0/SDO0_1
SDO1/SDO1_1
SDO2/SDI3
SDO3/SDI2
SDO4/SDI1
SDO5/SDI0
SCKT_1
FST_1
SCKR_1
FSR_1
SDO4_1/SDI1_1
SDO5_1/SDI0_1
HREQ
SCK/SCKL
SS/HA2
MISO/SDA
MOSI/HA0
HTRQ
HRD
HWR
HRRQ
SLAVE_ID_2
SLAVE_ID_1
SLAVE_ID_0
FCLK
BCLK
MCLK
RF_TXD_LSB
RF_TXD_MSB
RF_TXD_REF
RF_RXD_MSB
HOUSE_ID
ADDA_DATA
LED1
LED0
RF_RXD_LSB
+3.3V
GND
RF_TX_ON
RF_CONTROL_CLK
RF_CONTROL_LATCH
LED2
R771
30K
C767
68pF
TP836
CP_DRIVE
CP_DR_D
260636-04
J704
A
B
C
D

FIG. 5C-1

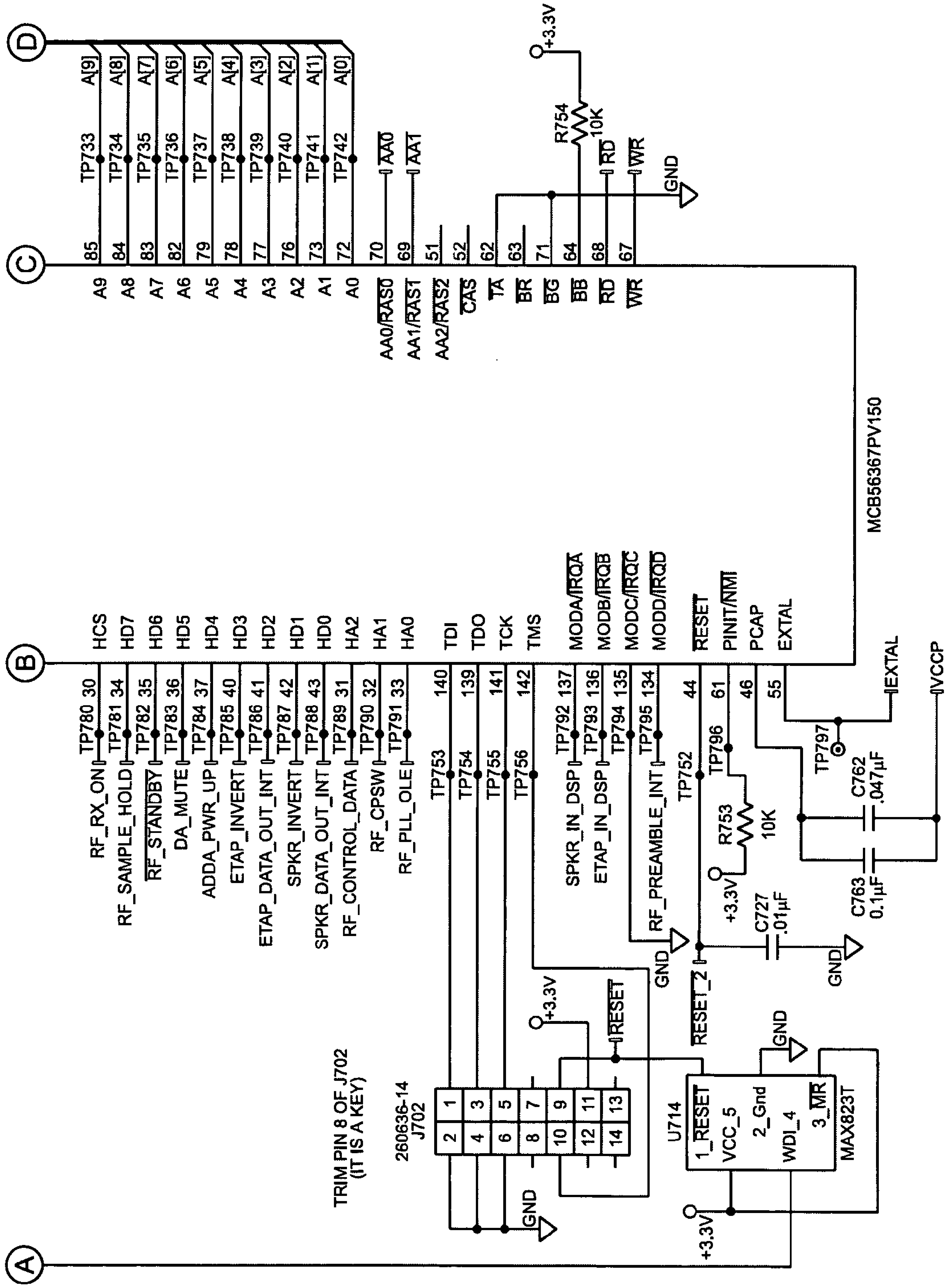

A
B
C
D
MCB56367PV150
A9
A8
A7
A6
A5
A4
A3
A2
A1
A0
AA0/RAS0
AA1/RAS1
AA2/RAS2
CAS
TA
BR
BG
BB
RD
WR
A[9]
A[8]
A[7]
A[6]
A[5]
A[4]
A[3]
A[2]
A[1]
A[0]
TP733
TP734
TP735
TP736
TP737
TP738
TP739
TP740
TP741
TP742
R754
10K
+3.3V
GND
HCS
HD7
HD6
HD5
HD4
HD3
HD2
HD1
HD0
HA2
HA1
HA0
TDI
TDO
TCK
TMS
MODA/IRQA
MODB/IRQB
MODC/IRQC
MODD/IRQD
RESET
PINIT/NMI
PCAP
EXTAL
VCCP
RF_RX_ON
RF_SAMPLE_HOLD
RF_STANDBY
DA_MUTE
ADDA_PWR_UP
ETAP_INVERT
ETAP_DATA_OUT_INT
SPKR_INVERT
SPKR_DATA_OUT_INT
RF_CONTROL_DATA
RF_CPSW
RF_PLL_OLE
SPKR_IN_DSP
ETAP_IN_DSP
RF_PREAMBLE_INT
TP752
TP753
TP754
TP755
TP756
TP796
TP797
R753
C727
.01µF
C762
.047µF
C763
0.1µF
RESET_2
TRIM PIN 8 OF J702
(IT IS A KEY)
260636-14
J702
U714
1_RESET
VCC_5
2_Gnd
WDI_4
3_MR
MAX823T

FIG. 5C-2

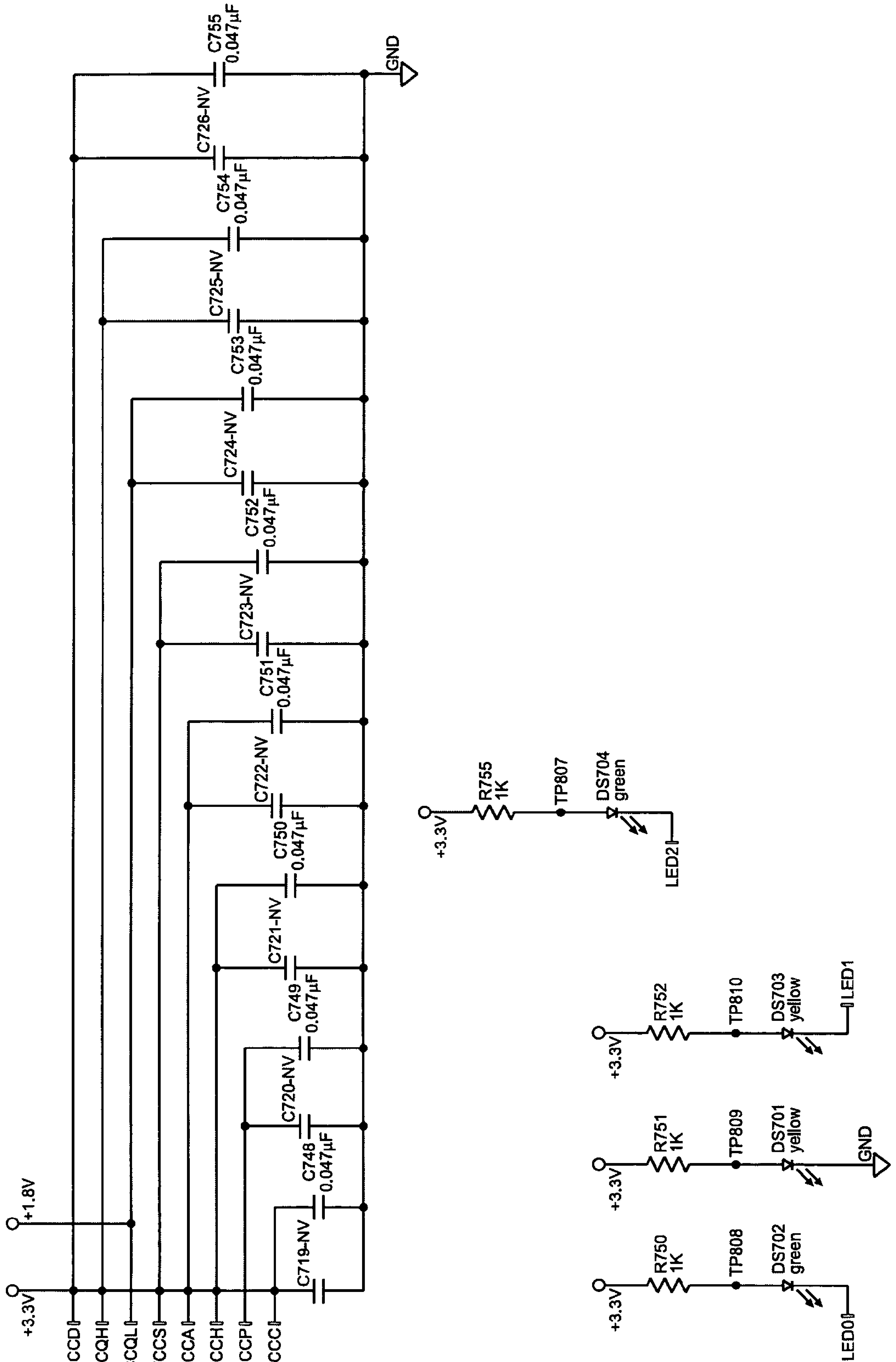

C755
0.047μF
GND
C726-NV
C754
0.047μF
C725-NV
C753
0.047μF
C724-NV
C752
0.047μF
C723-NV
C751
0.047μF
C722-NV
C750
0.047μF
C721-NV
C749
0.047μF
C720-NV
C748
0.047μF
C719-NV
+1.8V
+3.3V
VCCD
VCCQH
VCCQL
VCCS
VCCA
VCCH
VCCP
VCCC
+3.3V
R755
1K
TP807
DS704
green
LED2
+3.3V
R752
1K
TP810
DS703
yellow
LED1
+3.3V
R751
1K
TP809
DS701
yellow
GND
+3.3V
R750
1K
TP808
DS702
green
LED0

FIG. 5C-3

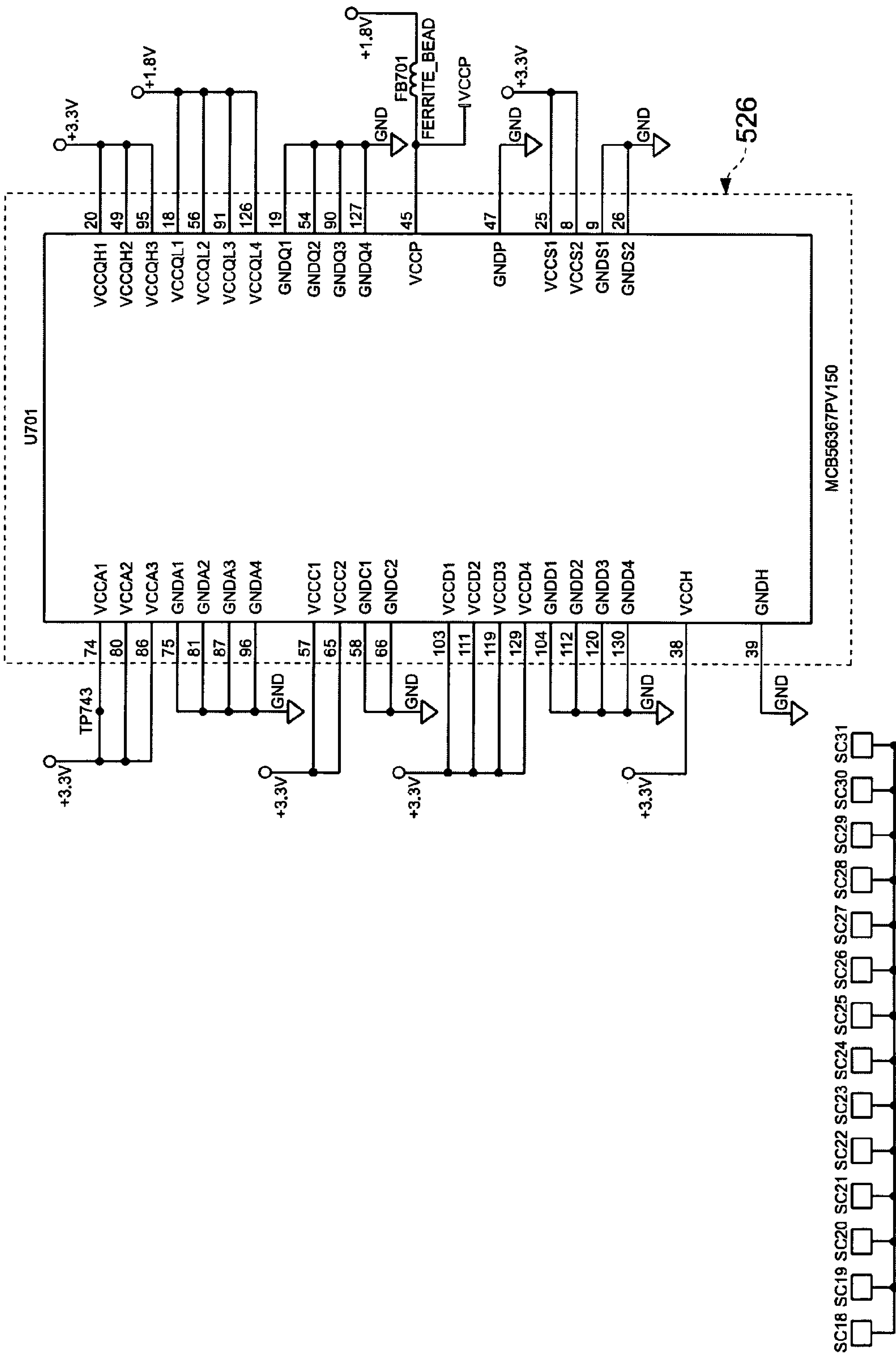

U701
MCB56367PV150
526
+3.3V
+1.8V
GND
FB701
FERRITE_BEAD
VCCP
TP743
VCCQH1 20
VCCQH2 49
VCCQH3 95
VCCQL1 18
VCCQL2 56
VCCQL3 91
VCCQL4 126
GNDQ1 19
GNDQ2 54
GNDQ3 90
GNDQ4 127
VCCP 45
GNDP 47
VCCS1 25
VCCS2 8
GNDS1 9
GNDS2 26
VCCA1 74
VCCA2 80
VCCA3 86
GNDA1 75
GNDA2 81
GNDA3 87
GNDA4 96
VCCC1 57
VCCC2 65
GNDC1 58
GNDC2 66
VCCD1 103
VCCD2 111
VCCD3 119
VCCD4 129
GNDD1 104
GNDD2 112
GNDD3 120
GNDD4 130
VCCH 38
GNDH 39
SC18 SC19 SC20 SC21 SC22 SC23 SC24 SC25 SC26 SC27 SC28 SC29 SC30 SC31

FIG. 5C-4

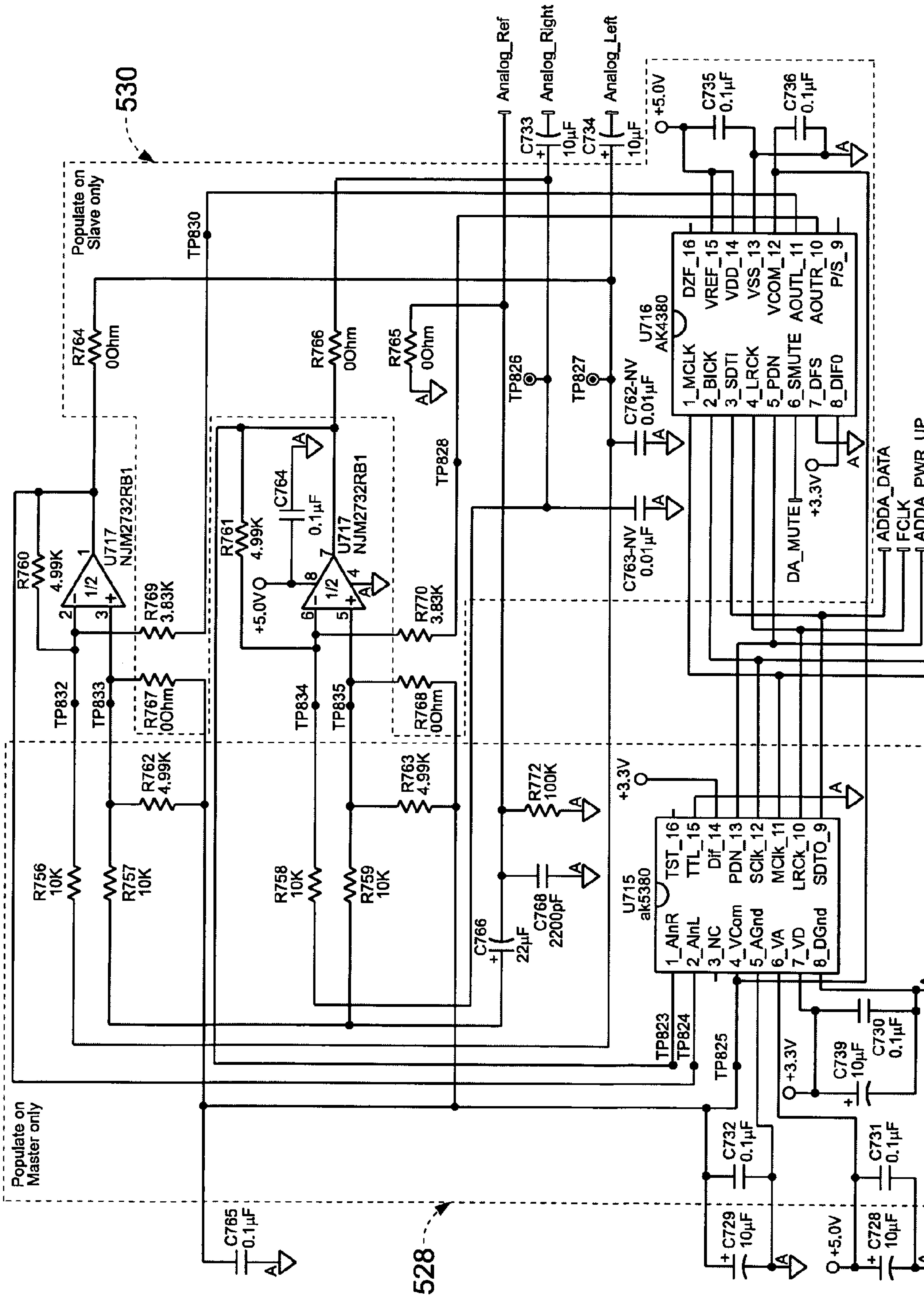

530
528
Populate on Slave only
Populate on Master only
Analog_Ref
Analog_Right
Analog_Left
+5.0V
+3.3V
U716
AK4380
1_MCLK
2_BICK
3_SDTI
4_LRCK
5_PDN
6_SMUTE
7_DFS
8_DIF0
DZF_16
VREF_15
VDD_14
VSS_13
VCOM_12
AOUTL_11
AOUTR_10
P/S_9
U715
ak5380
1_AInR
2_AInL
3_NC
4_VCom
5_AGnd
6_VA
7_VD
8_DGnd
TST_16
TTL_15
Dif_14
PDN_13
SClk_12
MClk_11
LRCk_10
SDTO_9
U717
NJM2732RB1
DA_MUTE
ADDA_DATA
FCLK
ADDA_PWR_UP
BCLK
MCLK
C733 10µF
C734 10µF
C735 0.1µF
C736 0.1µF
C762-NV 0.01µF
C763-NV 0.01µF
C764 0.1µF
C765 0.1µF
C766 22µF
C768 2200pF
C728 10µF
C729 10µF
C730 0.1µF
C731 0.1µF
C732 0.1µF
C739 10µF
R756 10K
R757 10K
R758 10K
R759 10K
R760 4.99K
R761 4.99K
R762 4.99K
R763 4.99K
R764 0Ohm
R765 0Ohm
R766 0Ohm
R767 0Ohm
R768 0Ohm
R769 3.83K
R770 3.83K
R772 100K
TP823
TP824
TP825
TP826
TP827
TP828
TP830
TP832
TP833
TP834
TP835

FIG. 5D

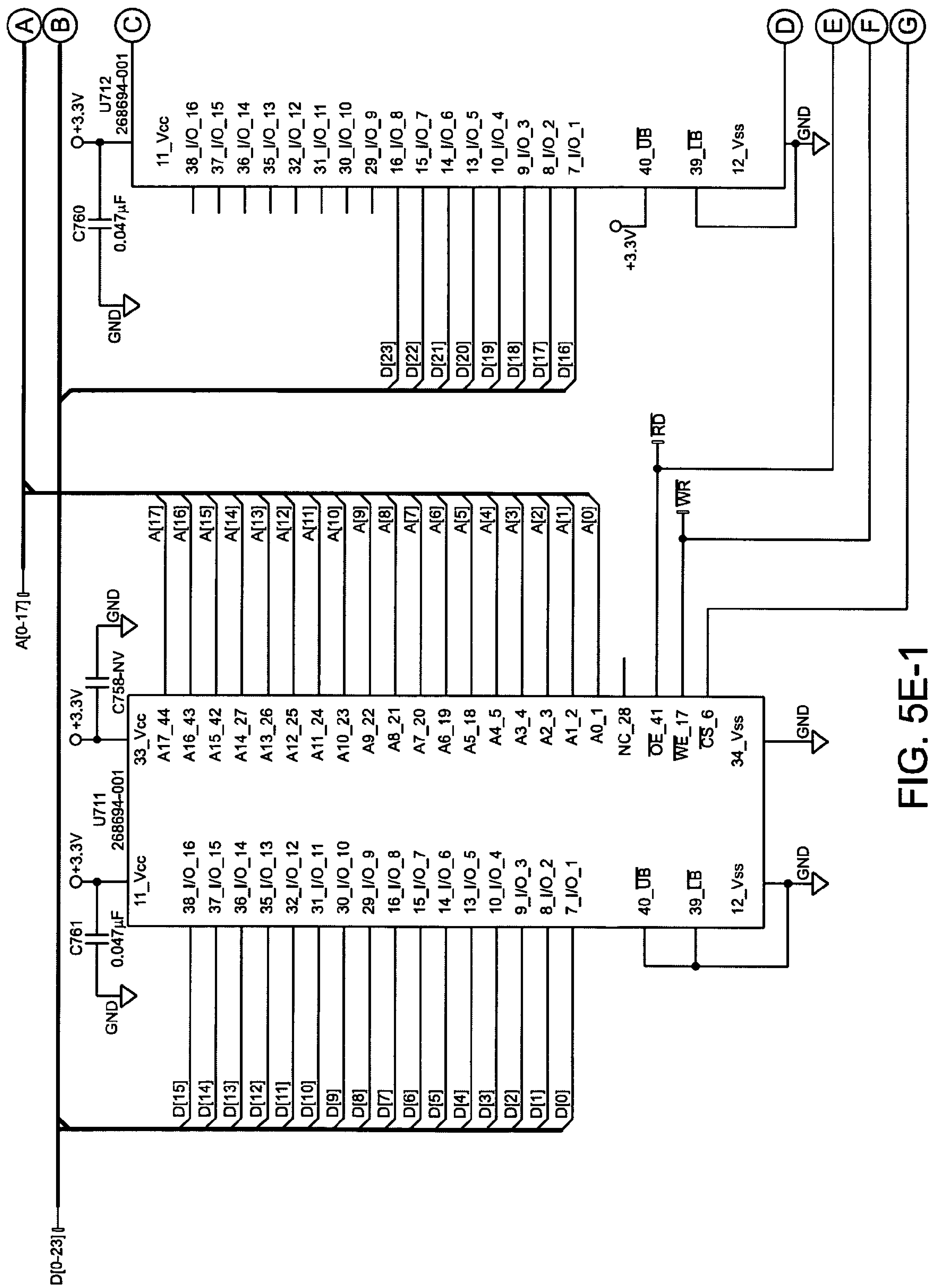
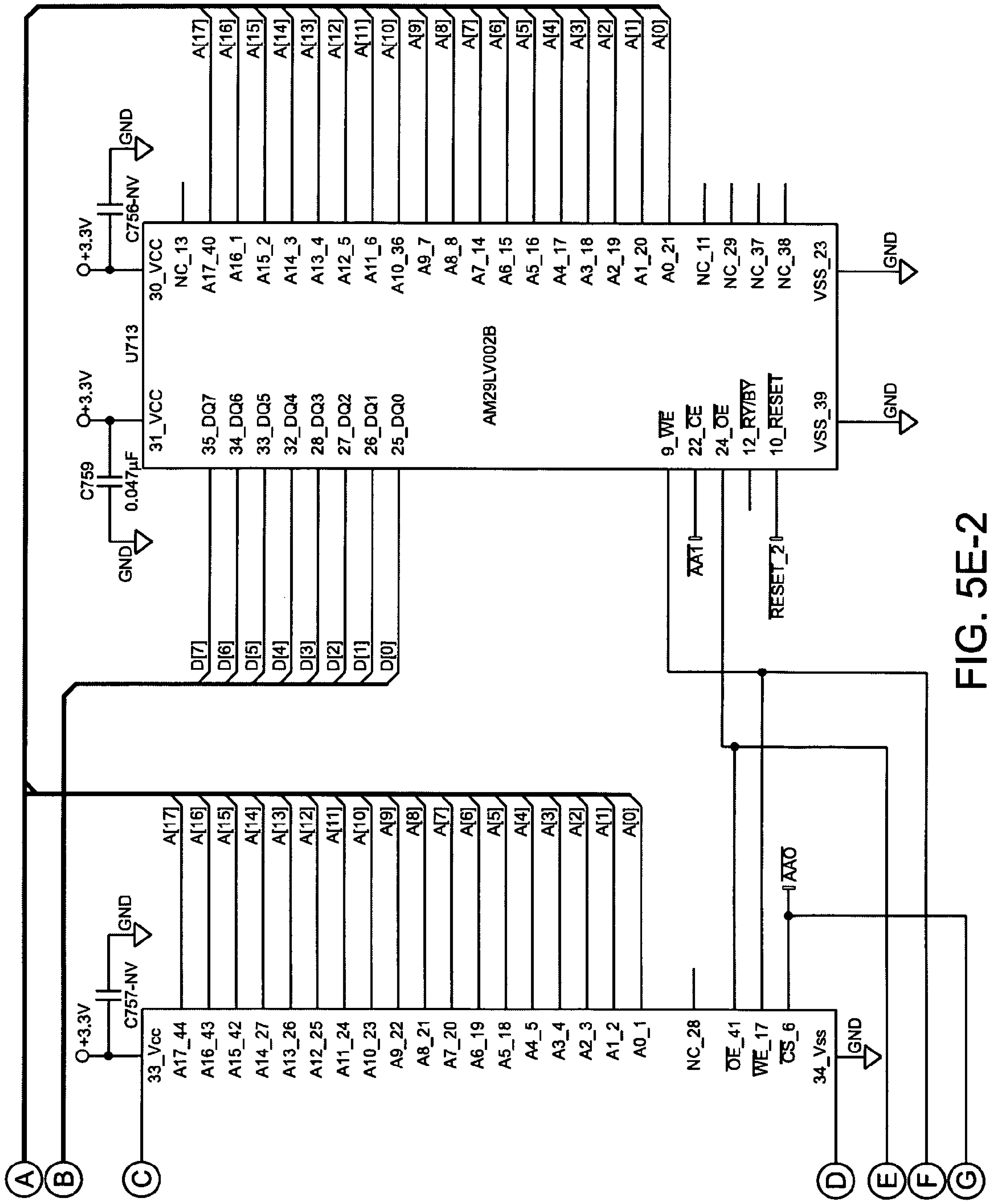

U712
268694-001
U711
268694-001
C760
0.047μF
C761
0.047μF
C758-NV
+3.3V
GND
A[0-17]
D[0-23]
RD
WR
11_Vcc
33_Vcc
12_Vss
34_Vss
40_UB
39_LB
NC_28
OE_41
WE_17
CS_6

FIG. 5E-1


U713
AM29LV002B
+3.3V
GND
C756-NV
C759
0.047µF
30_VCC
31_VCC
NC_13
A17_40
A16_1
A15_2
A14_3
A13_4
A12_5
A11_6
A10_36
A9_7
A8_8
A7_14
A6_15
A5_16
A4_17
A3_18
A2_19
A1_20
A0_21
NC_11
NC_29
NC_37
NC_38
VSS_23
35_DQ7
34_DQ6
33_DQ5
32_DQ4
28_DQ3
27_DQ2
26_DQ1
25_DQ0
9_WE
22_CE
24_OE
12_RY/BY
10_RESET
VSS_39
AA1
RESET_2
A[17]
A[16]
A[15]
A[14]
A[13]
A[12]
A[11]
A[10]
A[9]
A[8]
A[7]
A[6]
A[5]
A[4]
A[3]
A[2]
A[1]
A[0]
D[7]
D[6]
D[5]
D[4]
D[3]
D[2]
D[1]
D[0]
C757-NV
33_Vcc
A17_44
A16_43
A15_42
A14_27
A13_26
A12_25
A11_24
A10_23
A9_22
A8_21
A7_20
A6_19
A5_18
A4_5
A3_4
A2_3
A1_2
A0_1
NC_28
OE_41
WE_17
CS_6
34_Vss
AA0
A
B
C
D
E
F
G
FIG. 5E-2

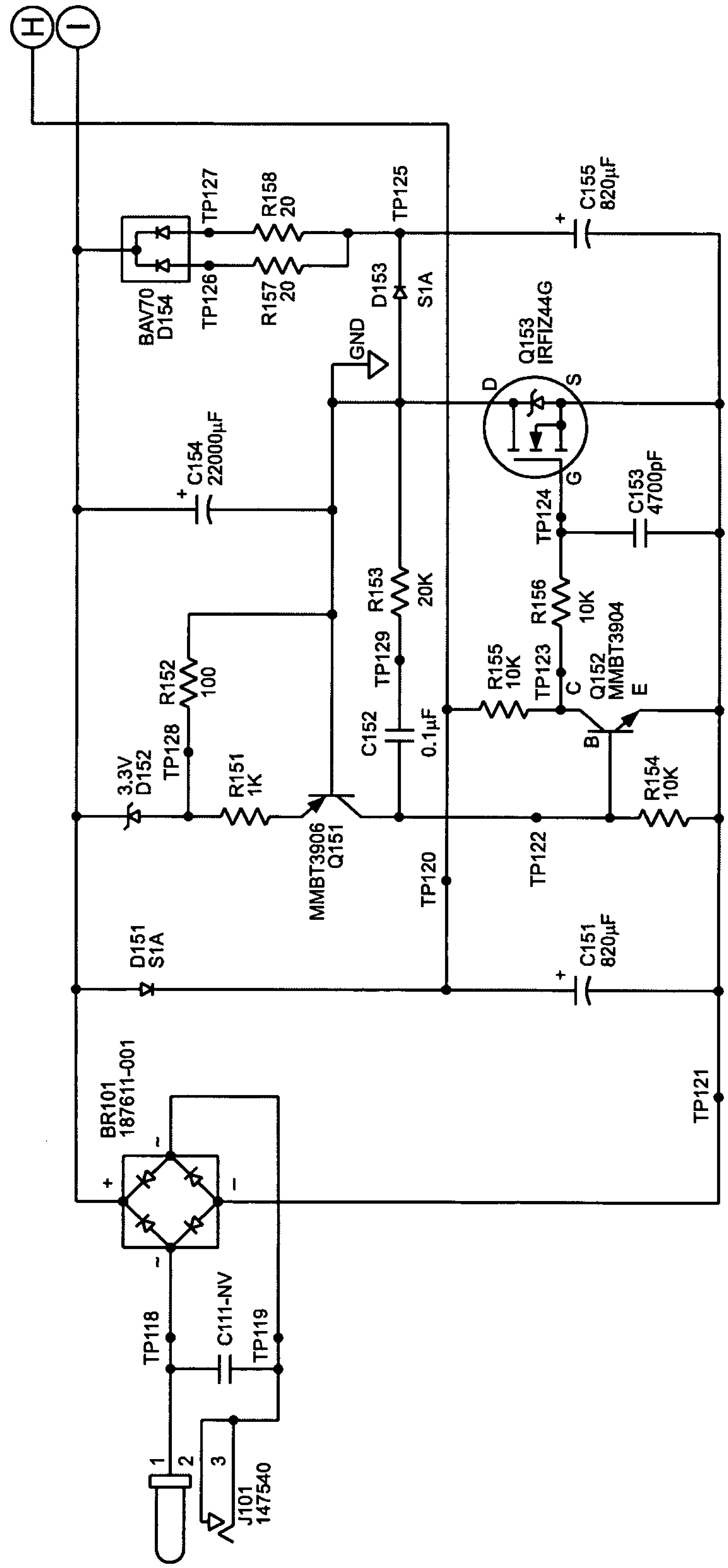
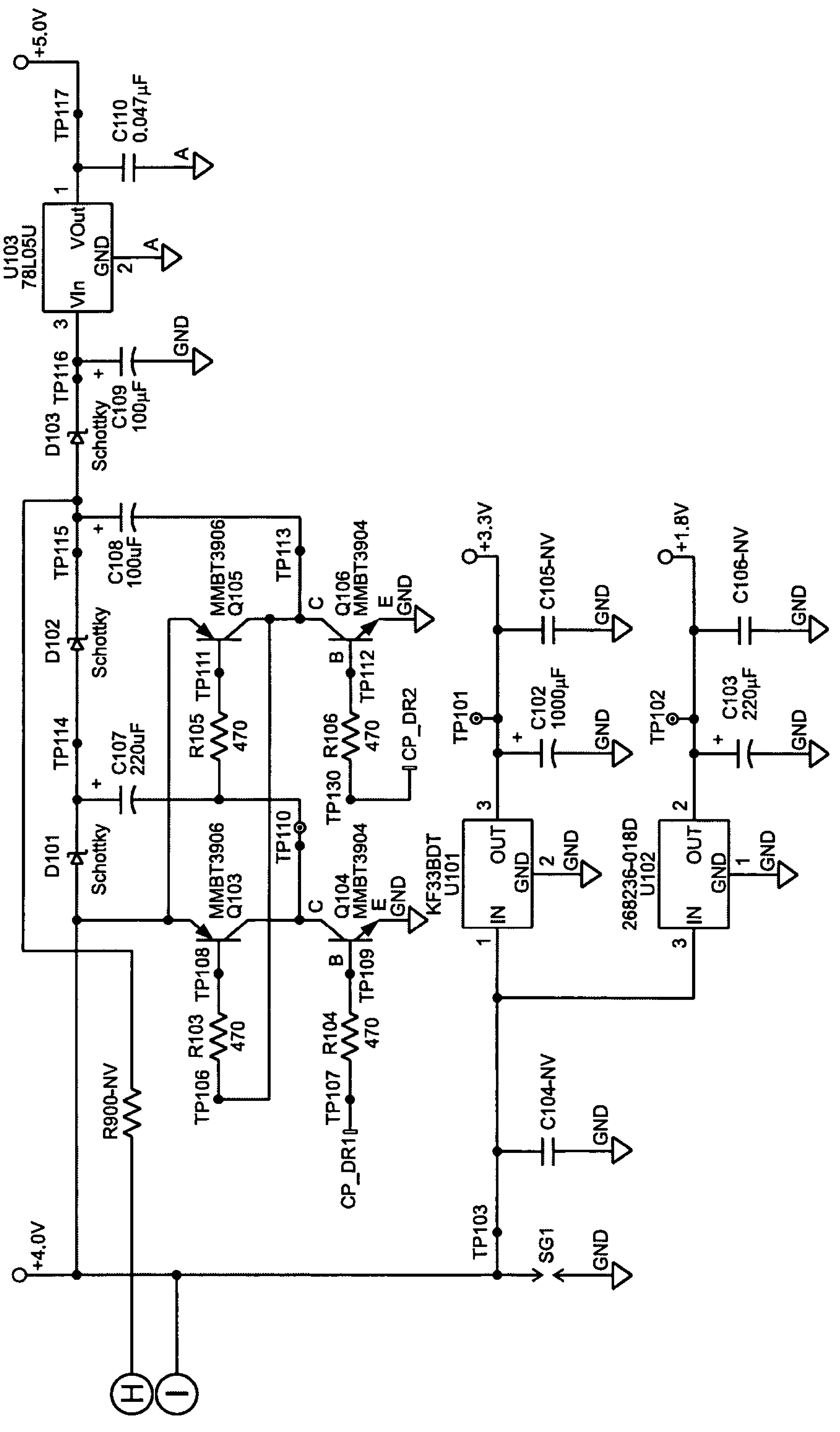

H
I
BAV70
D154
TP127
TP126
R158
20
R157
20
TP125
D153
S1A
C155
820µF
GND
Q153
IRFIZ44G
D
S
G
C154
22000µF
TP124
C153
4700pF
R153
20K
R156
10K
R152
100
TP129
R155
10K
TP123
C
Q152
MMBT3904
E
B
3.3V
D152
TP128
R151
1K
C152
0.1µF
R154
10K
MMBT3906
Q151
TP120
TP122
D151
S1A
C151
820µF
BR101
187611-001
TP121
TP118
C111-NV
TP119
1
2
3
J101
147540

FIG. 5E-3



+5.0V
TP117
C110
0.047µF
A
U103
78L05U
VIn
GND
VOut
1
2
3
TP116
C109
100µF
GND
D103
Schottky
TP115
C108
100uF
D102
Schottky
TP114
C107
220uF
D101
Schottky
MMBT3906
Q105
TP113
Q106
MMBT3904
C
B
E
GND
TP111
R105
470
TP112
R106
470
CP_DR2
TP130
MMBT3906
Q103
TP110
Q104
MMBT3904
TP108
R103
470
TP109
R104
470
TP106
TP107
CP_DR1
R900-NV
+4.0V
+3.3V
C105-NV
TP101
C102
1000µF
KF33BDT
U101
IN
GND
OUT
+1.8V
C106-NV
TP102
C103
220µF
268236-018D
U102
C104-NV
TP103
SG1
H
I

FIG. 5E-4

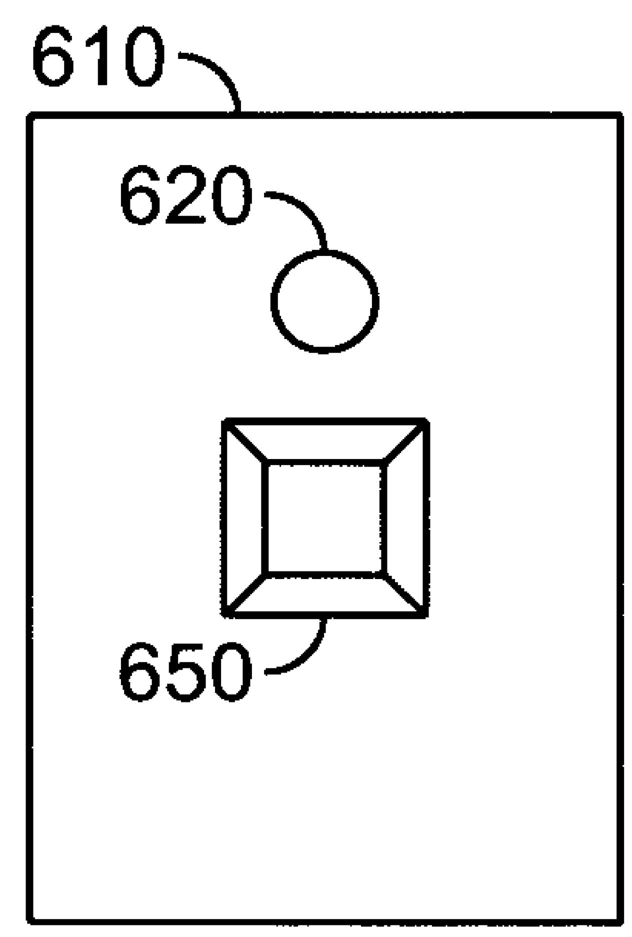

610
620
650

FIG. 6

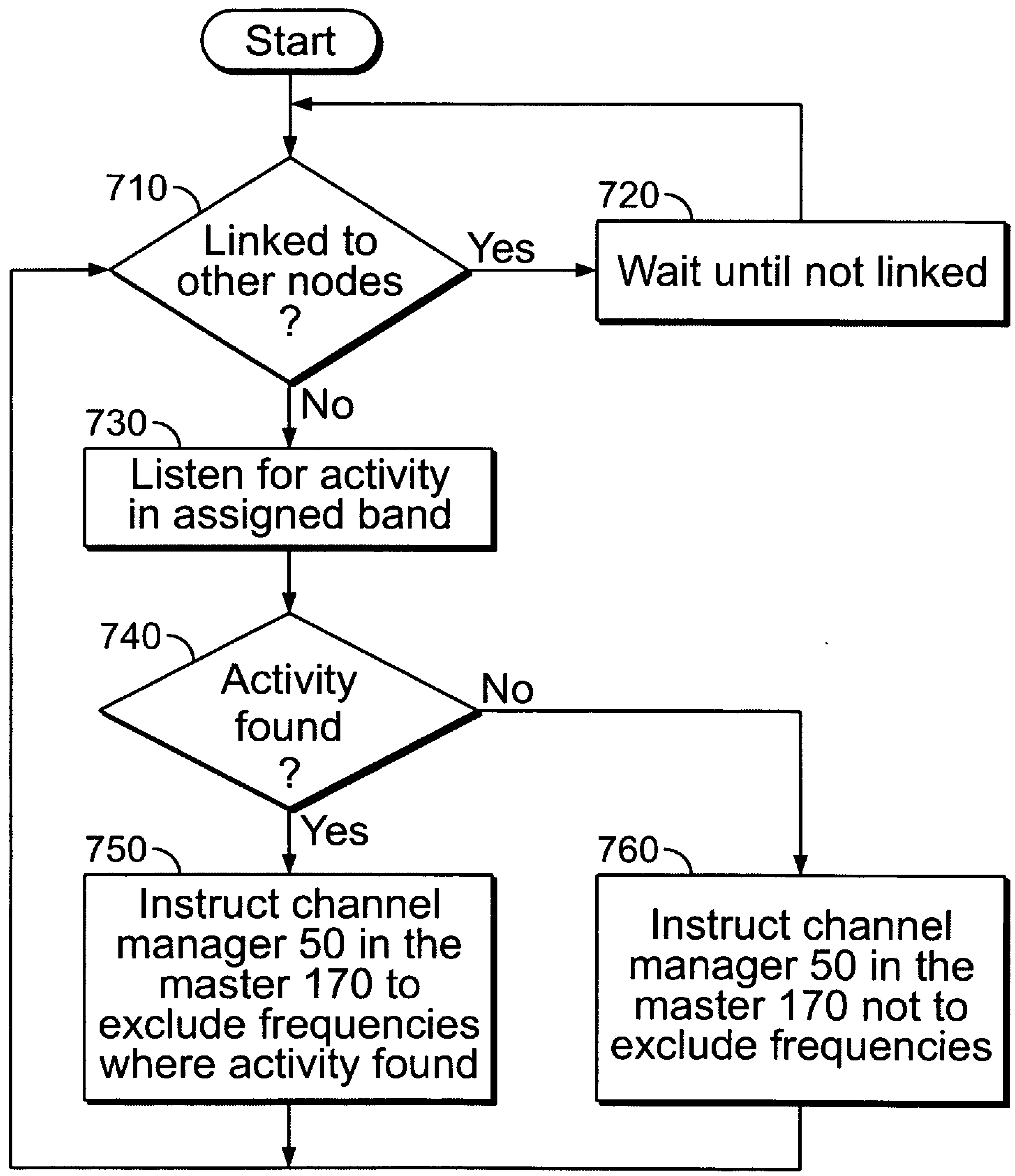

Start
710
Linked to other nodes ?
Yes
720
Wait until not linked
No
730
Listen for activity in assigned band
740
Activity found ?
No
Yes
750
Instruct channel manager 50 in the master 170 to exclude frequencies where activity found
760
Instruct channel manager 50 in the master 170 not to exclude frequencies

FIG. 7

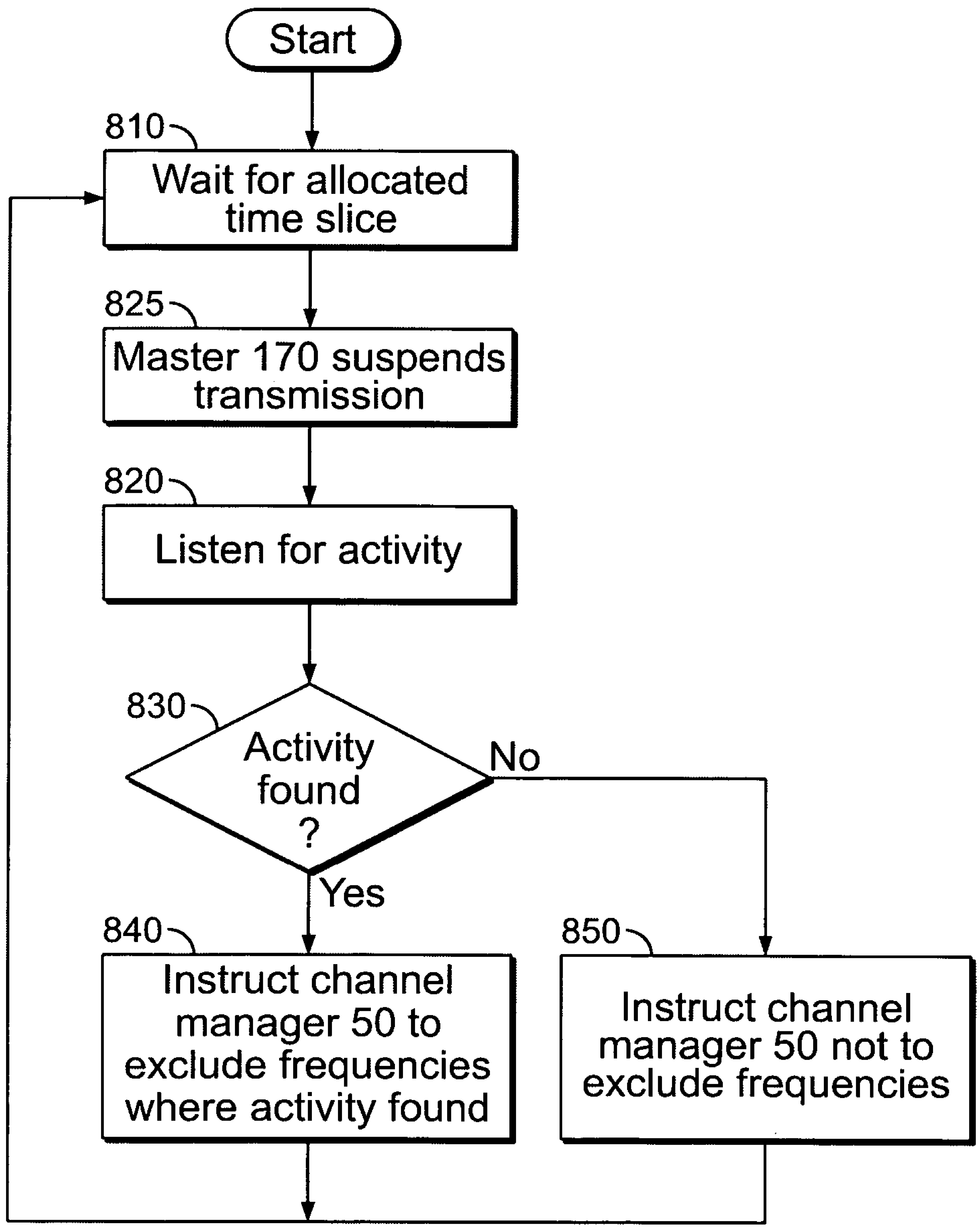

Start
810
Wait for allocated time slice
825
Master 170 suspends transmission
820
Listen for activity
830
Activity found ?
No
Yes
840
Instruct channel manager 50 to exclude frequencies where activity found
850
Instruct channel manager 50 not to exclude frequencies

FIG. 8

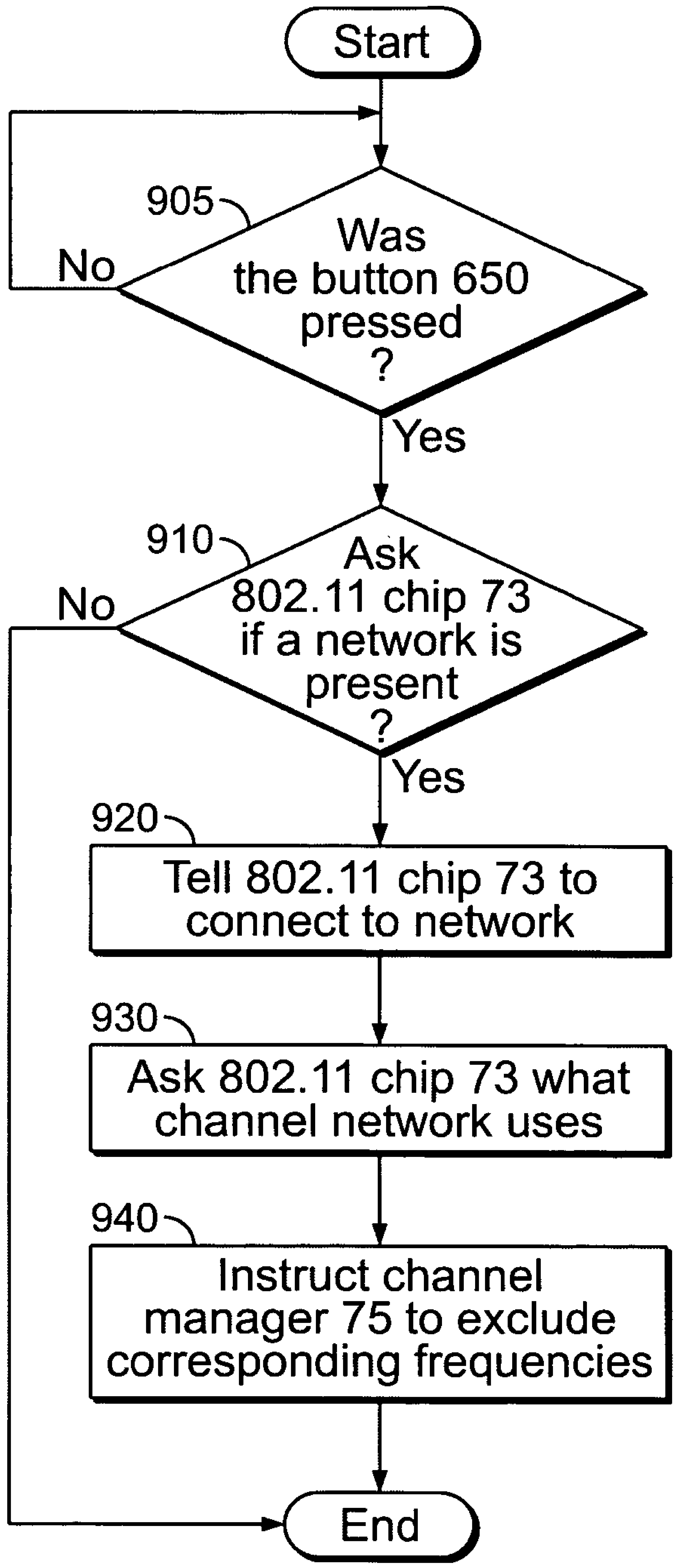

Start
905
Was the button 650 pressed ?
No
Yes
910
Ask 802.11 chip 73 if a network is present ?
No
Yes
920
Tell 802.11 chip 73 to connect to network
930
Ask 802.11 chip 73 what channel network uses
940
Instruct channel manager 75 to exclude corresponding frequencies
End

FIG. 9

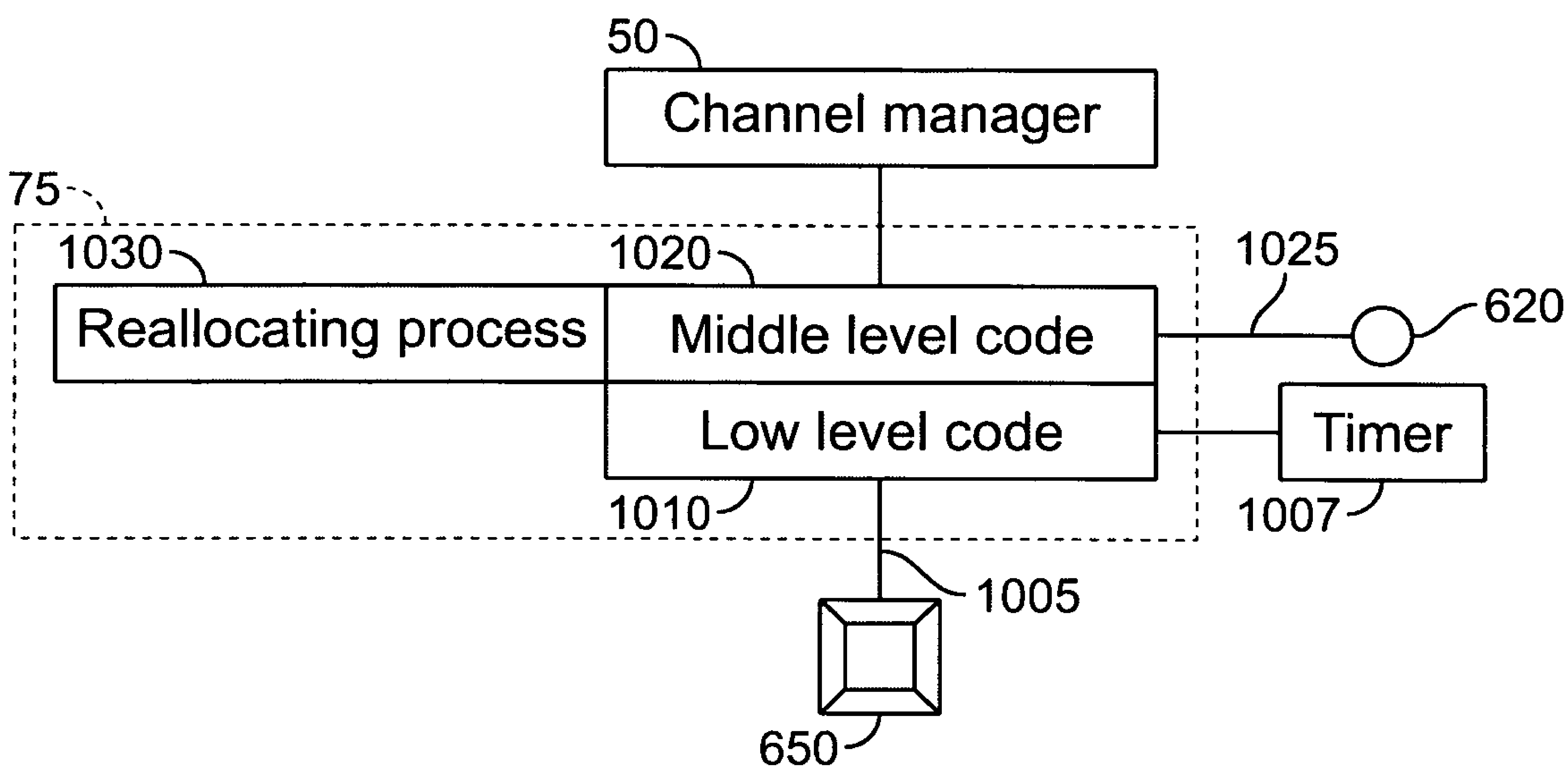

50
Channel manager
75
1030
Reallocating process
1020
Middle level code
1025
620
Low level code
Timer
1010
1007
1005
650

FIG. 10

METHOD AND APPARATUS FOR AVOIDING WIRELESS AUDIO SIGNAL TRANSMISSION INTERFERENCES

This is a continuation-in-part of U.S. application Ser. No. 10/640,215, filed Aug. 12, 2003, and incorporated by reference in its entirety.

The description relates to wireless communicating.

BACKGROUND

Wireless communicating is utilized in wide ranging applications, for example, in cellular phones, controlling devices, and exchanging data signals among two or more devices.

DEFINITIONS

Master: A node on the network that is in control of how communications will be managed between itself and a set of slaves.

Slave: A node on the network that communicates with a master.

Primary Data: The information that is presented to the master for the purpose of reliably transmitting representative signals to one or more of the slaves.

Ancillary Data: Data that is presented to a master or a slave represented by signals to be transmitted to another node on the network, with possibly poorer reliability and latency than that of the primary data.

Management Data: Data represented by signals that are transmitted across the network for the purpose of maintaining the performance of the network.

Transmission Parameter: A controllable characteristic that affects the performance of the communication system (for instance: signal power, center frequency, modulation technique, phase, antenna direction, antenna directivity, antenna position, signal polarization, time slot, equalizer setting, chipping sequence, and other characteristics).

Transmission Configuration: One or more transmission parameters with an associated value (e.g., signal power—200 mW, center frequency—2450 MHz, Modulation technique—4FSK.)

Transmission Quality Aggregation: A process whereby a node, such as the master on the network, develops its transmission quality estimation based at least in part on the transmission quality estimations of other nodes in the network.

Preferred Configuration List: A list of different transmission configurations that are used or intended to be used in the short term for transmission.

Preferred Frequencies: Frequencies of transmission included in the transmission configurations of the preferred configuration list.

Potential Configuration List: A list of transmission configurations that are not used nor intended to be used in the short term for transmission, but could potentially be used at some point in the future for that purpose.

Potential Frequencies: Frequencies of transmission included in the transmission configurations of the potential configuration list.

Packet: A collection of data signals that are transmitted contiguously using the same transmission configuration.

Block: A collection of packets containing data signals that together can be independently decoded by an error correction decoder. A block will preferably be transmitted using a variety of transmission configurations so as to average out the effects of localized channel degradation.

Frame: A collection of blocks and management packets that are transmitted using the preferred configuration list.

Stream: A contiguous flow of data bit signals that together represent the information from a single source (such as audio from FM radio or a CD player). A stream can contain more than one channel (such as left and right).

Signature: A characteristic emission of a wireless system.

Wireless system: A single wireless device, or multiple wireless devices capable of communicating wirelessly with one another.

Other terms are defined in context in the body of the specification.

SUMMARY

In one aspect, in general, the invention features a method comprising a second wireless system determining a frequency of active operation of a first wireless system, and communicating wirelessly on the second wireless system in the vicinity of wireless communication on the first wireless system, the wireless communication utilizing a spread-spectrum technique that excludes the determined frequency.

Implementations may include one or more of the following features: The determining is done at a time when transmissions from the first wireless system cannot be detected by the second wireless system. The determining is done at a time when transmissions from the first wireless system do not impede the functionality of the second wireless system. The determining is done at a time when transmissions from the second wireless system do not impede the functionality of the first wireless system. The determining is done at a time when the second system is not transmitting. The second system comprises a node, and the determining is done at a time when the node is not transmitting. The determining comprises receiving from a user information associated with the frequency to be determined. The information comprises an identification of a communication channel of the first wireless network. The information is received through a manual user interface. The manual user interface comprises a button. The manual user interface further comprises a visual indicator. The determining comprises detecting activity of the first wireless system. The determining comprises connecting to the first wireless system. An additional step may be added of deriving a channel of operation of the first wireless system. The determining comprises recognizing a signature of the first wireless system. An additional step may be added of suspending wireless communication on the second wireless network, and during the suspending, determining a frequency of operation of the first wireless system. The first wireless system comprises an IEEE 802.11 wireless network.

In another aspect, in general, the invention features a method comprising maintaining for a second wireless network, information about a frequency in use by a first wireless network, communicating on the second wireless network using a spread-spectrum technique, and controlling the spread-spectrum technique to exclude the frequency associated with the maintained information.

Implementations may include one or more of the following features: The information is updated periodically. The information is obtained from a user through a user interface. The information is obtained automatically by observation of the first wireless network.

In another aspect, in general, the invention features an apparatus comprising an identifier device to determine information about frequencies in use by a first wireless network, a transmitter device to transmit using a spread-spectrum technique, and a controller to cause the transmitter device to avoid the determined frequencies by the second wireless network. The identifier device comprises a manual user interface.

In another aspect, in general, the invention features an apparatus comprising means for determining information about frequencies in use by a first wireless network, and means for avoiding the determined frequencies by the second wireless network using a spread-spectrum technique.

Other features and advantages will become apparent from the following description and from the claims.

DESCRIPTION

FIG. **1** shows a function block diagram of one implementation of the invention;

FIG. **2**A shows the data signal structure from the output of the payload manager;

FIG. **2**B shows the block structure from the error correction codec;

FIG. **2**C shows a CRC protected packet structure;

FIG. **3** shows the flowchart of system operation procedure of one implementation of the invention;

FIG. **4**A shows the flowchart of operation procedure for network acquisition at the master;

FIG. **4**B shows the flowchart of operation procedure for network acquisition at the slave; and

FIG. **5**A-**1**-**3**, FIG. **5**B**1**-**2** FIGS. **5**C-**4**, D, E are schematic circuit diagrams of an exemplary embodiment of the invention;

FIGS. **7**-**9**; are flow charts illustrating exemplary processes according to the invention, and

FIGS. **6**-**9**; and

FIG. **10** is a black diagram of channel selector **75**.

With reference now to the drawing, FIG. **1** is a block diagram illustrating the logical arrangement of a system **4** according to the invention. A master **170** communicates with at least one slave, such as slave **180**, via a wireless medium (not shown). The system **4** is not limited to one master or one slave; multiple masters **170** can transmit to multiple slaves **180**. For simplicity, the following description will be based on an example of one master **170** and multiple slaves **180**. The slaves **180** are generally located in multiple distributed locations. The slaves **180** can be located in a plurality of rooms, each having a utilization device, such as a speaker, connected to it. While this specific example relates to a sound system, other applications are contemplated, such as video, multimedia, telemetry, and remote data gathering applications). The slaves **180** can be battery powered and/or portable, such as in a headset.

Information signals **160** to be transmitted from the master **170** to the slaves **180**, such as digital audio information signals, are first processed by payload manager **10** to provide a data unit signal to be used as input to error correction coder **20**, functioning to present information signals to a communication channel so as to reduce the channel's negative impact on data integrity. The master can further include a source coder **5** for providing compression (an audio compressor, for instance). A variety of techniques can be employed for audio compression: for example, Audio Layer 2 (AC2) compression as described in ISO/MPEG-1; AC3 Psychoacoustic masking and Redundancy reduction. For example, for 16-bit, 2 audio channel, 32.55 kHz audio information signals, the master can include a source coder, such as an apt-x coder from APT—Audio Processing Technology (headquartered in Belfast, N Ireland).

The output from the Apt-x coder is organized by payload manager **10** into a data signal structure typically containing one hundred seventeen Message Words with six Symbols per Message Word and 4-bits per symbol in 2808 bits. This data signal structure can be represented by a matrix having six columns and one hundred seventeen rows, as shown in FIG. **2**A. Each entry in the matrix is a symbol with 4-bits, and each row in the matrix is a "message word" (a unit of input to error correction encoder **20** which will be described in more detail below). The output from payload manager **10** along with some management bits (such as multiplexing control signals) can be protected using a channel coding technique such as error correction coding. The error correction encoder **20** maps a message word into a code word. Reed-Solomon (RS) coding can be used. For the exemplary RS coding in this example, the bit rate of the output from the error correction encoder **20** is doubled with respect to its input. The output of error correction encoder **20** (a block) can also be represented in the form of a matrix as shown in FIG. **2**B. Each entry of the matrix is a symbol having 4 bits, and each row of the matrix is a code word composed of 12 symbols. For the exemplary audio signal, the block as output from error correction encoder **20** is a matrix having 12 columns and 117 rows. Each column of the matrix is defined as a packet having 468 (117×4) bits.

Error detection can be implemented by adding Cyclic Redundancy Checks (CRCs) or checksums into each packet after error correction coding. The CRCs can be distributed within the packet so that it is possible to tell not only if the packet contains an error, but also what part of the packet contains the error. Specifically, for the exemplary wireless audio home application, each packet is further divided into a number of (four, for this example) sub-packets (each has 117-bits), and a 4-bit CRC is individually calculated on each sub-packet (as shown in FIG. **2**C). For the 4-bit CRC in this example, corrupted data will have a 1/16 chance of falsely passing. The CRCs are further multiplexed by inserting each CRC close to the sub-packet it protects (either preceding or following the sub-packet). By doing so, the location of an error within a packet can be better located. The output from error correction encoder **20** is then processed by a packetizer **25**. The output from packetizer **25** is transmitted to the slaves by the wireless interface **30** via one or more antennas **40**.

From one transmission configuration to another, channel capacity can vary due to factors such as path loss, multipath interference, any interference other than the multipath interference, and nonlinearities. The system **4** can control how it uses the communication medium by changing its controllable transmission parameter values. The system **4** can in effect perform averaging over some or all of the controllable transmission parameters to compensate for localized channel capacity degradation. For example, localized channel capacity degradation can sometimes be caused by multipath interference which renders some pieces of spectrum unusable. If frequency is a controllable transmission parameter, the averaging can be achieved by sending the primary data over a sufficiently large number of frequencies and relying on error correction coding to repair the errors in packets sent over the affected spectrum.

Different transmission parameters are allowed to take on different values. For example, the frequency parameter can take on one value from the discrete set of radio frequencies that are tunable by the Phase Locked Loop (PLL). For the polarization parameter, the range of values can be the choice of vertical or horizontal polarization. The transmission quality achieved for a certain transmission configuration can be measured as the quality of the information signals received at the slave **180** (when the information is transmitted using the specified transmission configuration). The transmission quality can be quantified by many metrics such as Bit Error Rate (BER) which can be estimated based on information present in the error correction decoder and from the CRCs.

For the exemplary wireless application, the communication channel between a master **170** and slave **180** is the wireless medium with its associated multipath characteristics and interference sources. The controllable transmission parameter is the carrier frequency. The range of transmission parameter values depends on the selected frequency spectrum and channel bandwidth. For example, for an RF medium in the 2.4 GHz ISM (the Industrial, Scientific and Medical) radio band, the range of parameter values for the carrier signal control variable embraces all the tunable frequencies within the ISM radio band. The transmission configurations are the frequencies that can be adjusted by varying the transmission parameter value (carrier signal frequency, for this example). The following description is based on the exemplary wireless application.

Referring back to FIG. **1**, a number of blocks (each containing multiple packets) from the output of error correction encoder **20** can be further processed and organized by packetizer **25** into a frame containing the blocks and management packets. The management packets will be described in more detail below. For the exemplary wireless application, eleven blocks from error correction encoder **20** and two management packets are organized into a frame having one hundred thirty-four packets.

The output from packetizer **25** is then transmitted via the wireless interface **30** using digital modulation techniques such as Frequency-Shift Keying (FSK), Quadrature Amplitude Modulation (QAM), Phase-Shift Keying (PSK), or Amplitude Shift Keying (ASK), from the master **170** to the slaves **180** using the 40 frequencies on the preferred frequency list. Since there are ninety-four tunable frequencies in the 2.4 GHz band, this choice leaves fifty-four frequencies on the potential frequency list. For this example, a frame contains 102.4 μs of audio data signals. A packet within a frame lasts about 750 μs. Error correction encoder module **20** can further perform interleaving in the time and frequency domains such that each symbol in a code word from the error correction encoder **20** is distributed to a different packet (as shown in FIG. **2**B) to be transmitted on a different frequency from the preferred frequency list. The interleaving enables the error correction decoder **90** in the slave **180** to average the good quality of some packets with the poor quality of other packets such that the original information is accurately reconstructed. Interleaving can be performed over time, over frequency, or over any other controllable transmission parameter. Furthermore, each packet within a frame can be transmitted on a different frequency (transmission configuration in general)—in essence, introducing averaging in the frequency domain. A block as a whole is then transmitted over a representative portion of the available frequencies.

The system **4** is not limited to a specific form of source coder **5** and payload manager **10**. The basic function of source coder **5** and payload manager **10** along with error correction encoder **20** and packetizer **25** can include dividing the information signals to be transmitted into a plurality of data signal units such as blocks for channel coding. The function can also include interleaving. The use of modules payload manager **10**, error correction encoder **20** and packetizer **25** are for the purpose of illustration. These functional modules can be implemented in one or multiple physical units in the form of hardware or software. The invention is not limited to the specific source coder (such as Apt-x source coder in the exemplary implementation), specific structure of the data units (such as blocks and frames as illustrated) and specific error correction coder (such as RS coding in the exemplary implementation). The described data structures as shown in FIG. **2**A and FIG. **2**B are also for illustration purpose only.

Also shown in FIG. **1** is the slave **180** which can include one or more antennas **150** along with the wireless interface **80** for receiving the information transmitted from the master **170**. The received information is fed to the depacketizer **185** and then to the error correction decoder **90**. The depacketizer **185** and error correction decoder **90** perform essentially the inverse functions of packetizer **25** and error correction encoder **20**. In the error correction decoder **90**, each code word of every received block is checked for errors using the information inherent in the error correction coding, for example, the RS coding and the CRCs. The symbols in each code word will be flagged as correct or erroneous. If CRCs are present, they can be used to flag a group of symbols as "erasures" as is well known in the art of error correction coding. The transmission quality estimation provided by channel quality estimator **130** will be described in more detail later) is sent back to the master **170** via the wireless channel. The channel quality aggregator **70** in the master **170** collects this information for use by the channel manager **50** to select subsequent sets of frequencies (preferred frequency lists) used for transmitting primary data signals. The decoded information from error correction decoder **90** is sent to the payload manager **100**. A source decoder **105** can be further provided for performing essentially the inverse function of source coder **5** for audio data signal transmission. The information signals can then go through the digital/analog converter **110** for the exemplary wireless application and be fed to the speaker **120**.

The modules in the block diagram of FIG. **1**, depicting the system **4**, (e.g., source coder **5**, payload manager **10** and channel manager **50**, etc.), are logical modules that can be aggregated together in one or more physical modules, such as in the form of either hardware modules like ASICs and/or software modules.

The system estimates the channel transmission quality for both the preferred frequency list (preferred configuration list in general) and the potential frequency list (potential configuration list in general). The potential frequency list, for this example, can include all available frequencies (besides the 40 RF frequencies from the preferred frequency list) selected from the 2.4 GHz ISM frequency band. Although this detailed description focuses on the exemplary wireless application, the system **4** has broader applicability, and is not limited to a single controllable transmission parameter but is applicable to multiple controllable transmission parameters, including but not limited to time, frequency, wavelength, polarization, antenna directivity, antenna direction, antenna location, equalizer settings, chipping sequence, signal power, and signal phase. In general terms, the system monitors the transmission quality for the preferred configuration list which will be used for transmitting primary data signals, and the potential configuration list which is not expected to be used for transmitting primary data signals in the immediate future.

Referring back to FIG. **1**, each one of the slaves **180** develops its own transmission quality estimation in **130** by keeping track of the symbol-error information determined in its error correction decoder **60** for the preferred frequency list. For the potential frequency list, estimation of the transmission quality can be done by sending a probe packet containing data signals known a priori by both the master **170** and the slaves, such as slave **180**. The probe packets are transmitted on probe frequencies selected from the potential frequency list. The transmission quality for the probe frequencies is estimated in each slave by measuring, such as the BER, of the received probe data. The probe frequencies are not currently-in-use, but the master **170** needs to know their transmission quality so that they can be used as candidates along with the preferred frequency list when the system **4** selects subsequent preferred frequency lists for transmitting subsequent primary data signals. The set of probe frequencies can include all or a subset of the frequencies from the potential frequency list. The transmission quality estimate for both the set of 40 frequencies on the preferred frequency list and the set of probe frequencies can be sent back to the master in a feedback packet. Due to a variety of phenomena, such as multipath interference, each one of the set of 40 frequencies can behave differently in terms of transmission quality. One advantageous choice of frequency for transmitting the feedback packet is the frequency from the preferred list which has the highest transmission quality, although many other choices, such as alternately using frequencies having higher than average transmission quality are also possible.

To improve performance, frequency (transmission configuration in general) adaptation is used. The master collects the feedback data signals from all of the slaves and aggregates its own transmission quality estimate. The master then periodically adjusts the preferred frequency list (or in general, the preferred configuration list) for the subsequent primary data signals. There are many different ways in which the master can aggregate the transmission quality information from the slaves **180** and select the subsequent preferred frequency list. For instance, it can simply average the estimate reported by each slave **180** for each frequency. The master **170** can also use the transmission quality information from each slave **180** to estimate the quality of the link to each slave **180**, and then make decisions about which frequencies to use in the future based on the needs of a slave **180** which is closest to failure. In general, the master **170** can process the transmission quality measurements and select the subsequent preferred frequency list which improves a function of the transmission quality of all master/slave pairs. Based on the transmission quality estimation and how the master **170** selects the subsequent preferred frequency list, the preferred frequency list can not need to be adjusted, or the adjustment (from current preferred frequency list to subsequent preferred frequency lists) can be pseudorandom, partially pseudorandom or the adjustment can be nonrandom.

Although the system described thus far is effective at recovering from outside interference, in some circumstances it may interfere with other communications systems. Moreover, the approach thus far described represents a reactive approach, in which interference must have already occurred in order for the system to compensate for it. An additional, proactive approach is also possible, in which the system can be instructed to avoid interference from another network, and avoid interfering with another network, before the interference has happened.

For example, with reference to FIG. **1**, another local wireless network **190** may exist in the same frequency range as the system described. As a more specific example, a user may have a WiFi network (a wireless network conforming to the IEEE 802.11 standard) in the same vicinity as the described system. A WiFi network includes one or more nodes, such as computers and/or base stations, all of which transmit in the same 2.4 GHz range as does the exemplary system described above although what is described is also applicable to other frequency bands. In certain configurations, the WiFi network may be more affected by the described system than the system is by the WiFi network.

To address this situation, the channel manager **50** also takes into account information from a channel selector **75** in determining the preferred and, optionally, potential frequency lists. (Although the channel selector **75** is shown separately in FIG. **1**, it may also be part of the channel manager or part of another element or device in the system.) The channel selector **75** determines frequencies that should not be included among the preferred and, optionally, potential frequencies, because the determined frequencies may interfere with the other local wireless network **190**.

With reference to FIGS. **1** and **6**, in some implementations, the channel selector **75** includes a user interface **610** that has a visual indicator **620**, such as an LED, and a button **650**. Each time the user presses the button **650**, the indicator **620** flashes once. This signifies to the user that the system has registered the button press. Each time the user presses the button **650**, the channel selector **75** selects a WiFi channel (a frequency band utilized by an IEEE 802.11 wireless network) to avoid. By default, before the user has pressed the button **650**, the channel selector **75** selects WiFi channel **6** to avoid, since channel **6** is the most common channel in use in WiFi networks. When the user presses the button **650** once, the channel selector **75** selects WiFi channel **11**, since that is the second-most common WiFi channel. Each subsequent time the user presses the button **650**, the channel selector **75** selects WiFi channels **2-5**, followed by **6-10**. If the user again presses the button **650**—or if, at any time, the user holds down the button **650** for three seconds—the channel selector **75** will switch to "full band" mode, in which it does not avoid any WiFi channel. In this case, the indicator **620** flashes multiple times.

In other implementations, multiple indicators exist such that the currently-selected WiFi channel may be unambiguously displayed. For example, in some implementations, a display exists showing the WiFi channel number. In some implementations, the user controls the selected channel through DIP switches. In some implementations, the user controls the selected channel through an on-screen graphical user interface or an LCD-based graphical user interface.

In some implementations, more than one WiFi channel may be selected at once.

The user may know in advance which channel is in use by the other network **190**, in which case he or she can press the button **650** the correct number of times to select the required channel. Alternatively, the user may simply press the button **650** when the other network **190** is experiencing interference. Repeated presses of the button **650** will eventually cause the channel selector **75** to select the correct channel to avoid.

The channel selector **75** communicates the information about which WiFi channel has been selected to the channel manager **50**, which excludes the associated frequencies from the preferred and, optionally, potential frequency lists. For example, if the user has selected WiFi channel **6**, the channel manager **50** will exclude frequencies corresponding to WiFi channel **6**, i.e, 2.426 to 2.448 GHz, from the preferred frequency list, and optionally the potential frequency list as well.

In other implementations, the channel selector **75** includes a mechanism by which the channels occupied by other devices operating on the 2.4 GHz frequency range can be automatically detected and avoided. Referring to FIG. **7**, for example, the channel selector **75** first waits until the master **170** is not linked to other nodes (steps **710** and **720**), for example, to a slave node. Then, the channel selector **75** listens for activity on frequencies within the 2.4 GHz frequency band (step **730**). If the channel selector **75** finds activity (step **740**), it instructs the channel manager **50** excludes those frequencies from the preferred and, optionally potential frequency lists (step **750**); otherwise the channel manager **50** determines that the entire band is available (step **760**). In some variations, instead of waiting until the master **170** is not linked to other nodes (steps **710** and **720**), the channel selector **75** instead waits until the button **650** (FIG. **6**) is pushed. In some variations, step **760** is not used; instead, the channel manager assumes that all frequencies within the band of operation may be included in the potential and preferred frequency list unless instructed otherwise. In some variations, the channel selector **77** located in a slave **180** is used in addition to a channel selector **75** located in a master **170**. In these variations, the slave's channel selector **77** sends the channel selector **75** in the master **170** information about what frequencies to instruct the channel manager **50** to exclude in step **750**. In some variations channel selectors **75**, **77** located in both the slave **180** and in the master **170** listen for activity. These variations are advantageous in that the slave's channel selector **77** may be able to detect frequencies that the master's channel selector **75** cannot.

In some implementations, referring to FIG. **8**, the master **170** periodically allocates small slices of time (for example, 150 microseconds) within the normal sequence of transmissions/receptions during which all nodes on the network are radio-silent. The channel selector **75** waits for the allocated time slice (step **810**). At this point, the master **170** suspends transmission (step **825**) while the channel selector **75** listens for activity (step **820**). If it finds activity (step **830**), the channel manager **50** excludes the frequencies at which the activity is occurring from the preferred frequencies (step **840**); otherwise the channel manager determines that the given frequencies are available (step **850**). In some variations, step **850** is not used; instead, the channel manager assumes that all frequencies within the band of operation may be included in the potential and preferred frequency list unless instructed otherwise.

In the implementations described in FIGS. **7** and **8**, the channel selector **75** listens for activity in one of following two exemplary ways. In one variation, the channel selector **75** successively tunes to each frequency (or channel) in the band and detects radio frequency energy. In a second variation, the channel selector **75** attempts to detect the signature of a device operating on the channel. As used herein, a signature represents a characteristic emission of a device. The signature may relate to an emission's frequency, duration, amplitude, phase, power level, antenna polarity, or other attributes, or a combination of attributes. In some implementations, the signature comprises "beacon" packets with a fixed duration associated with an 802.11 network, sent at regular intervals. In some implementations, the signature comprises bursts of energy at regular intervals. In some implementations, the signature comprises energy configured in swaths of 22 MHz, also characteristic of an 802.11 network. In some implementations, a signature comprises a modulation technique, for example ASK, FSK, QAM, OFDM, FHSS, or DSSS. In some implementations, other signatures are defined.

Referring to FIGS. **1** and **9**, in some implementations, a node such as the master **170** is capable of connecting to an 802.11 wireless network. In some variations the node connects, such as through a standard 802.11 chip **73**, to the 802.11 wireless network. In these variations, the connection can be initiated by the user, such as when the user pushes a button. In this case, the channel selector **75** checks to see if the button **650** was pressed (step **905**). If not, it waits until the user presses the button. (Note that the button press described here does not cause the same effect as the button press described in the text referring to FIG. **6**.) Next, the channel selector **75** checks to see if an 802.11 network **190** is present (step **910**). If a network exists, the channel selector **75** instructs the 802.11 chip **73** to connect to the network (step **920**) and, using the 802.11 protocol, to ascertains the channel on which the network is operating (step **930**). The channel selector **75** then instructs the channel manager **50** to exclude the frequencies associated with the detected channel (step **940**). In some variations, the channel selector **75** checks to see if a node such as the master **170** is connected to other nodes such as the slave nodes **180**. If it is, it waits until it is not connected before searching for a wireless network.

In some variations, the master **170** performs the process described in FIG. **9** by omitting step **905** altogether. Instead, the master **170** begins at step **910**. In some implementations, it performs this process when it is first turned on. In some implementations, it performs this process at prespecified time intervals, for example, every 3 seconds. In some variations, the master **170** suspends transmission while it is performing the process described.

In other examples, the other network **190** need not be a WiFi network but could be any network on which communication may interfere with the system. Other techniques may be used to solicit the user's input on the frequencies to be avoided, or to obtain that information automatically.

In some implementations, the channel selector **75** is a software program implemented on a DSP ("digital signal processor"). Referring to FIG. **10**, the button **650** (FIG. **6**) is attached to a pin **1005** on the DSP. The channel selector **75** consists of two layers of software code: a low level **1010** and a high layer **1020**. Code in the low level **1010** monitors the voltage on the pin **1005**. A voltage of 0 indicates that the button **650** is depressed; a voltage of non-0 (for example, 3.3 volts) indicates that the button **650** is not depressed. The low-level code **1010** constantly monitors the status of the pin **1005**. The middle-level code **1020** constantly monitors the status of the low-level code **1010**. When the voltage on the pin **1005** becomes non-zero, the low-level code returns an indication that the button has been pressed. It does not continue to return this result until the voltage becomes zero, then non-zero again. (Otherwise, it would send multiple messages whenever the button **650** is pressed.)

The low-level code **1010** also maintains a timer **1007**, which the code **1010** uses to determine when the button **650** has remained pressed for three seconds or more. When this happens, the low-level code **1010** returns an indication to the middle-level code **1020** that the button has been pressed. This indication, and the indication that the button has been pressed, take the form of arbitrary patterns. In some examples, the indication that the button is not pressed is binary '00'; the indication that the button is pressed is '01,' and the indication that the button has been pressed for three seconds is '11'.

The indicator **620** is connected via a pin **1025** to the DSP. When the middle-level code **1020** receives a positive result (indicating that the button **650** has been pressed) from the low-level code **1010**, the middle-level code **1020** briefly sends a signal on pin **1025** to flash the indicator **620** once. The middle-level code **1020** then updates an internal channel ID list to mark the channel to avoid. If, after updating, the channel ID list indicates that the system should now be in full band mode, the middle-level code **1020** sends a signal on pin **1025** to flash the indicator **620** one or more additional times.

The channel manager **50** constantly monitors the status of the middle-level code **1020**. The middle-level code **1020** returns the frequencies that are associated with the selected WiFi channel. When the button **650** is pressed, the middle-level code **1020** initiates a process **1030** that reallocates all of the channels in the band according to the new selection.

The channel manager **50** updates the preferred and, optionally, the potential frequency lists based on factors described earlier as well as the result from the middle-level code **1020**.

Information about the selected subsequent preferred frequency list is included in the network management information which can be transmitted to the slaves **180**. To improve reliability of transmitting this information, the network management information can be further protected via error correction coding, which can be more certain of correction than that used to protect the primary data, along with the use of CRCs. Further, instead of sending the network management information once, during the transmission of a frame, the network management information can be transmitted multiple times. For the exemplary wireless audio application, since each frame contains 11 blocks, the network management information can be transmitted along with every block of data so the slaves will have 11 opportunities to receive it.

FIG. **3** shows a flowchart operation procedure **190** of the system **4**. The system start **200** organizes information signals into a first number of frames, each including a second number of packets **210**. Each frame is transmitted from the master **170** to the slaves **180** by sending **220** the packets within the frame via a preferred frequency list. The master **170** aggregates and selects a subsequent preferred frequency list based on transmission quality estimation between all the master/slave pairs for both the preferred frequency list and a set of probe frequencies chosen from the potential frequency list **230**. The procedure **190** continues until all the frames are sent **240**.

An adaptive scheme, which utilizes the transmission quality estimation, can be used along with a number of technologies for transmitting the digitally modulated information, e.g., FHSS, DSSS, and OFDM (selecting appropriate RF spectrum and digital modulation schemes), by adaptively adjusting one or more controllable transmission parameters. For example, in the case of frequency hopping (FHSS), the master **170** sends a short burst of data signals (a packet for the exemplary wireless sound system) via a digital modulation technique such as 4-level frequency shift keying (4-FSK) or quadrature amplitude modulation (QAM), then adjusts the frequency and sends another short burst of data signals. Each frequency is occupied for a brief period of time. The preferred frequency list can or can not be adaptively adjusted, based on transmission quality estimation and how the master **170** selects the frequencies, to accommodate the localized channel capacity variation. When the proposed transmission quality based adaptive scheme is used with direct sequence modulation (DSSS), the system **4** can take various actions based on transmission quality information, including switching to a new center frequency having better transmission quality, adjusting the chipping sequence, or changing other variables that can affect the transmission, such as antenna polarization, power level, and time slot. When the slaves **180** are handsets, the handset transmission power can also be adjusted so that signals of all handsets have the same power arriving at the master **170**.

In general, the monitored channel transmission quality information can be used in many different ways to improve system performance in addition to the adaptive adjustment of frequencies (transmission configurations in general) described above. For example, the properties of digital modulation can be adjusted based on monitored transmission quality. For a frequency having better quality, a higher order modulation scheme such as 16-QAM could be used, while for a frequency having poorer quality a lower order modulation scheme such as 4-QAM could be used, so as to equalize the BER on the frequencies.

The information signals **160** to be transmitted can include more than one stream of information signals simultaneously. For example, for the exemplary wireless sound system, there can be two streams from two separate audio signal sources (e.g., one might be carrying a radio broadcast while the other carries material from a CD player), allowing people in different rooms to listen to sounds from different audio signal sources simultaneously. The multiple streams can be separately coded and transmitted via separate masters, and the slaves will then choose to connect to one of the available masters. Alternately, the multiple streams can be multiplexed into the transmission of a single master. For the case when more than one stream is transmitted, the error correction coding scheme of coder **20** can also be adjusted based on the transmission quality and/or utilization of received streams (such as based on slave **180** status and user command/control for each stream). For example, when one stream is not used, an error correction scheme of coder **20** more certain of error correction can be used for the other stream. Furthermore, one embodiment can pack two of the masters **170** into a single physical unit, with each master **170** dedicated to a separate audio signal source (e.g., one for a radio broadcast, and the other for a CD player). They can share common components, such as a common power supply. Also, two masters **170** can be wire-connected in order to synchronize their transmissions and share preferred frequency lists. Two masters **170** that are so implemented are preferably synchronized so that they can listen for feedback packets at the same time. They can also coordinate their selection of frequencies to avoid transmitting on the same frequency at the same time.

The master **170** and the slaves **180** preferably agree on which frequencies (transmission configurations in general) will be used, especially for a broadcast network when either a new slave **180** or an existing slave **180** which lost synchronization with the network (e.g., due to interference), must be able to acquire the network (know which frequencies will be used for the next frame of data and synchronize its own time base with that of the master **170**), without disturbing any ongoing transmission to other slaves **180**. A set of predefined "base frequencies" can be used by the master **170** to transmit the information about the current preferred frequency list to the slaves **180**, and the information used by a new slave **180** for acquiring the network. The set of base frequencies is known a priori by both the master **170** and the slaves **180**, including the slave **180** to be attached. At a predetermined rate, the master **170** can transmit a "sync" packet on one of the base frequencies. The sync packet includes a timing reference extracted from the master's local clock (for instance, a local crystal oscillator) and the current preferred frequency list. When a new slave **180** is turned on, the slave **180** tunes to one of the base frequencies. The slave **180** repeatedly tries to receive the sync packet, and moves on to another one of the base frequencies, until it succeeds. The slave **180** then reads in the data and the CRC. If the CRC fails, the slave **180** resets itself and tries again. If the CRC passes, the slave **180** assumes it has acquired a master. The new slave **180** then receives packets from the master **170** until such time as the new slave **180** detects a loss of synchronization.

FIG. **4A** shows a process **290** for network acquisition at the master **170**. The process **290** start **300** selects one frequency from the set of preselected base frequencies **310** to be used for acquiring the network by the new slaves **180**. A COUNT variable is then reset **320**. Periodically (every 100 ms for example) the master **170** transmits a sync packet containing the master's timing reference and the subsequent preferred frequency list on the selected base frequency **330**. The COUNT variable is incremented **340**. If the COUNT variable is larger than a predetermined threshold value **350**, the procedure switches to select one frequency **310** to pick another frequency from the list of base frequencies. Otherwise the master **170** transmits the sync packet on the same selected base frequency. When the master **170** is not transmitting a sync packet (which is most of the time), it sends other packets containing other data signals.

FIG. **4**B shows a process **390** for network acquisition at the slaves **180**. The process **390** start **400** selects one frequency from the set of preselected base frequencies **410** to be used for acquiring the network by the new slaves **180**. A COUNT variable is then reset **420**. The new slave **180** seeking a master **170** for attachment tunes to the selected frequency and searches for the timing reference information **430** sent as part of the sync packet. If it succeeds, the process reads in the synchronization data **450**. Otherwise the COUNT variable is incremented **460**. If the COUNT variable is larger than a predetermined threshold value **470**, the process switches to select frequency **410** to select another frequency from the list of base frequencies. Otherwise, the procedure returns to **430** so the new slave **180** will continue trying to find a sync packet on the same base frequency. After reading the synchronization data **450**, its CRC is checked for validity **480**. If synchronization data is valid, synchronization has been achieved. The new slave **180** reads in subsequent packets **490**. Otherwise, the procedure returns to **460** to seek synchronization data again. After step **480**, the new slave receives primary data packets. If the received primary data packets are consistently incorrect **495**, the process returns to **410** to try to acquire the network again.

FIGS. **5**A-**5**E are exemplary schematic circuit diagrams suitable for use as a master **170** or a slave **180**. This circuitry can be connected as a master **170** and receive stereo signals from a source, such as a CD player or tuner, and function as a slave **180** that furnishes appropriate audio signals to a loudspeaker system.

The probe packet, feedback packet, and sync packet are a few possible management packets that can be implemented. The packet structure of such management packets can be the same as or different from the packet structure used for data signal transmission. An exemplary implementation of the invention accommodates one feedback packet per frame, with probe packets and sync packets each being sent every other frame.

The wireless system **4** can operate alone or in parallel with other types of existing networks such as Ethernet networks. For example, the wireless system can be used to transmit time critical data (e.g., audio signal streams) while the existing network is used to transmit other data signals (e.g., command/control signals).

An advantage of the wireless system **4** is that it can successfully operate in the presence of noise and competing data signal transmissions in the same transmission band (e.g., from microwave ovens, cell phones, wireless telephones, and other audio devices). For example, interference from microwave ovens, which can be a serious impediment to wireless data signal transmission in homes, is inherently rejected by the system's monitoring of transmission quality—frequencies affected by microwave oven are discovered and avoided. Competing wireless data transmissions are also, to a degree, dealt with in the same manner; and additional immunity to such competing transmissions arise by choosing sets of frequencies that have little overlap with the frequencies used by competing systems (e.g., the frequencies used in a frequency hopping implementation could be orthogonal to those of a competing system).

Each master **170** in the system can also be assigned a unique identification signal that can be transmitted to slaves **180** in the same system to condition the slaves **180** to receive correct data signals. Management packets returned by slaves **180** to masters **170** can be sent during time slots assigned on the basis of a slave's unique identification signal.

The system **4** is sufficiently reliable to provide a multiroom home wireless audio system with a range (distance between master and slaves) of more than 100-ft, as many as eight slaves; a latency (time delay between master and slaves) of less than 40 ms, excellent audio quality, and ability to accommodate transmissions from at least two independent audio signal sources.

The auxiliary data signals, such as command/control signals from the slaves can also be sent back to the master along with, or separate from, the transmission quality estimation information signals via the same or separate frequency. For example, for the exemplary wireless sound system application, the user can want to change the audio signals transduced by the speaker, such as by changing the FM radio station. For this example, the relatively long-range wireless link (up to more than 100 ft for the exemplary application) can operate beside short-range RF remote controls, with which the user can command the specific audio devices (e.g., changing the FM radio station). The user's command/control information can be relayed from the short-range RF remote to the master located at the other end of the long-range wireless link. When the RF remote operates in a different frequency spectrum from the wireless data transmission, the slaves where the audio device is connected can have an RF remote transceiver included so that the command/control to/from the RF remote can be passed through the long-range wireless link in the same way that ancillary information signals are transmitted. Essentially this arrangement forms a repeater for the short-range RF remote, enabling RF remote operation in the same area served by the long-range wireless link.

FIGS. **5A-1** includes a transceiver chip **500** commercially available from Atmel Corporation of San Jose, Calif. For transmission, the chip **500** receives a base band signal and FSK modulates this signal on a carrier in the 2.4 Ghz band tunable by a PLL on the chip. A digital interface receives appropriate signals for controlling the carrier frequency and other parameters. For reception, the chip **500** receives a signal in the 2.4 Ghz band, converts the signal for filtering, and then demodulates it to a base band signal delivered at **510**. Chip **502** can be regarded as a sibling chip of transceiver chip **500**. For transmission, it functions as a power amplifier, delivering as much as a few hundred mw of power for radiation of a modulated carrier in the 2.4 Ghz band. For reception, it includes a low noise amplifier.

A chip **504** is an analog switch that functions primarily for modulation and is commercially available from Atmel accepting two-level FSK modulation, and with supporting components, furnishes four-level FSK modulation. A chip **506** functions as an operational amplifier that coacts with one of the switches in analog switches **504** as a sample/hold circuit. This circuit accepts a reference level from an incoming analog signal at **510** so that the following circuitry can correctly differentiate one level from another to negate the effects of any DC bias in the incoming signal.

A data slicer **508** coacts with surrounding components to convert the analog signal at **510** into a digital signal that can be sampled.

Referring to FIGS. **5B-1** an oscillator **512** functions as the primary time base for furnishing timing signals to all other circuits in the embodiment. An analog audio interface **514** receives left and right stereo signals when the embodiment functions as a master, and a socket **516** is only populated when operating as a master. Switch bank **518** allows a user to select the identification signal for the specific master **170** or slave **180**.

Programmable logic device (PLD) **520** can be an EPM3032ATC44-10 commercially available from Altera of San Jose, Calif. The device **520** handles many low-level digital signal functions that are relatively easily handled with programmable logic. The device also performs the preamble detection. When the PLD detects a given pattern in the incoming signal (the preamble), it fires an interrupt signal which the digital signal processor uses as a timing reference. When used as a slave **180**, the master/slave interface can include these voltage translation transistors.

Referring to FIGS. **5**C-**1**-**4** a digital signal processor **526** performs the methods according to the system **4**. This digital signal processor in this exemplary embodiment is a 180-MIPS Motorola chip (Motorola DSP56367) commercially available from Motorola. Referring to FIG. **5**D, there is shown circuitry performing analog audio signal processing. For master **170**, circuit **528** includes a differential pre-amp followed by an A/D converter. The master **170** is capable of taking two analog streams (of two channels each), two pairs of differential amplifiers and two dual analog-to-digital converters. For slave **180**, circuit **530** has a single (dual) digital-to-analog converter followed by a pair of buffered amplifiers. Only one stream of two channel output is furnished for this example.

Referring to FIG. **5**E, there is a schematic circuit diagram of the power supply. The output of a transformer is full-wave rectified, processed and converted into a range of DC voltages used in the circuitry.

There has been described novel apparatus and techniques for wireless communicating. It is evident that those skilled in the art can now make numerous uses and modifications of an departures from the specific apparatus and techniques disclosed herein without departing from the inventive concepts. Consequently the invention is to be construed as embracing each and every novel feature and novel combination of features present in or possessed by the apparatus and techniques herein disclosed and limited only by the spirit and scope of the appended claims.

What is claimed is:

1. A method avoiding interference from a first wireless system operating on a first frequency in a first range of frequencies in which a second wireless system may operate using spread spectrum techniques that has a plurality of frequency ranges including the first range and other frequency ranges outside said first range comprising,

determining on the second wireless system the first frequency of active operation of the first wireless system, and

communicating wirelessly on the second wireless system in the vicinity of wireless communication on the first wireless system while preventing the second wireless system from operating in the first frequency range and utilizing a spread-spectrum technique that operates in a frequency range outside said first frequency range without replacing said first frequency range with another frequency range.

2. The method of claim **1** in which the determining is done at a time when transmissions from the first wireless system do not impede the functionality of the second wireless system.

3. The method of claim **1** in which the determining is done at a time when transmissions from the second wireless system do not impede the functionality of the first wireless system.

4. The method of claim **1** in which the determining is done at a time when the second wireless system is not transmitting.

5. The method of claim **1** in which the second wireless system comprises a node capable of transmitting, and the determining is done at a time when the node is not transmitting.

6. The method of claim **1** in which user manually selects the first frequency range to be excluded from operation by the second wireless system.

7. The method of claim **6** in which the user manually selects the first frequency range pressing a button to prevent the second wireless system operating in the first frequency range.

8. The method of claim **1** in which the determining comprises detecting activity of the first wireless system.

9. The method of claim **1** further comprising suspending wireless communication on the second wireless network, during the suspending, determining a frequency of operation of the first wireless system.

10. A method avoiding interference from a first wireless system operating on a first frequency in a first range of frequencies in which a second wireless system may operate using spread spectrum techniques that has a plurality of frequency ranges including the first frequency range and other frequency ranges outside the first range comprising,

maintaining for the second wireless system, information about the first frequency,

communicating on the second wireless system using a spread-spectrum technique in a frequency range outside said first range of frequencies, and

controlling communicating on the second wireless system to exclude the first frequency without replacing said first frequency with another frequency.

11. The method of claim **10** in which the information is updated periodically.

12. The method of claim **10** in which the second wireless system includes a user interface and a user enters the information through the user interface to manually exclude the first frequency.

13. The method of claim **10** in which the information is obtained automatically by observation of the first wireless network.

14. An apparatus comprising

a second wireless system constructed and arranged to use spread spectrum techniques in a plurality of frequency ranges including a first frequency range embracing a first frequency on which a first wireless system operates that would have interference if said second wireless system operated in said first frequency range

a controller to prevent operation of said second wireless system in said first frequency range without replacing said first frequency range with another frequency range.

15. The apparatus of claim **14** in which the controller comprises a manual user interface constructed and arranged to allow the user to manually prevent operation of said second wireless system in said first frequency range.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 8,442,019 B2
APPLICATION NO. : 11/050160
DATED : May 14, 2013
INVENTOR(S) : Trott et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page:

The first or sole Notice should read --

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 2007 days.

Signed and Sealed this
Twenty-third Day of May, 2017

Michelle K. Lee
Director of the United States Patent and Trademark Office